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# PROCEEDINGS OF THE INDIANA ACADEMY OF SCIENCE

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# A GROWING SUBSTRATE FOR REARING BULK POPULATIONS OF HESSIAN FLY IN SELECTION OF RESISTANT WHEATS

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ABSTRACT: The use of an appropriate growing substrate for wheat plants is important for mass production of Hessian fly pupae. Potting soil (1/3 sand, 1/3 peat moss, and 1/3 top soil) was compared with a peat-lite mix, a commercial mixture of shredded peat moss and vermiculite. The number of Hessian fly pupae produced doubled in the peat-lite mix, perhaps due to better aeration and a more stable moisture level in the growing medium.

## INTRODUCTION

The medium selected for growing wheat seedlings to be infested with Hessian fly (HF), *Mayetiola destructor* Say (Diptera: Cecidomyiidae), is very important for the mass production of larvae in the greenhouse for testing wheat lines for resistance to specific biotypes of this insect (Foster, *et al.,* 1988). A greenhouse test was conducted to evaluate the effectiveness of the two soil types as rearing media for HF larvae.

## MATERIALS AND METHODS

An experiment was conducted for testing the effect of the soil substrate on the Hessian fly. Twelve greenhouse flats were seeded with wheat cv. "Monon" and were infested with HF biotype E. A potting soil (1/3 sand, 1/3 peat moss, and 1/3 top soil) was used in six flats, and a commercially available growing medium (JiffyMix$^{(R)}$) consisting of shredded peat moss and vermiculite was used in the other six.

The wheat seedlings were infested with HF when they were at the 1-2 leaf stage (see Foster, *et al.,* 1988). One hundred seedlings were then sampled at random 21 days after infestation on each medium. The pupae per plant were counted and measured.

## RESULTS AND DISCUSSION

The mean number of pupae per plant and the mean pupal size are presented in Figure 1. The number of pupae per plant was 8.24 on the commercial mixture, compared with 4.10 on the traditional potting soil mixture. The mean pupal size, however, was similar for wheat seedlings growing on either potting soil or peat-lite mix.

The mean number of pupae per plant were also grouped into frequency classes (Fig-

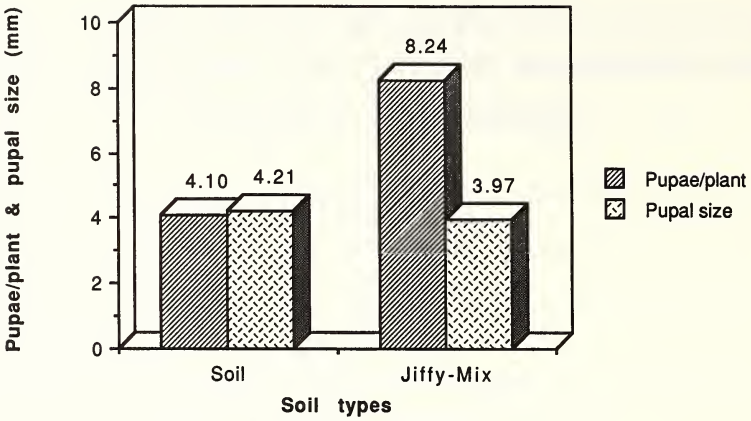

Figure 1. Numbers of pupae per plant and pupal size (mm) obtained from Hessian fly-infested wheat seedlings growing on potting soil or on peat-lite mix.

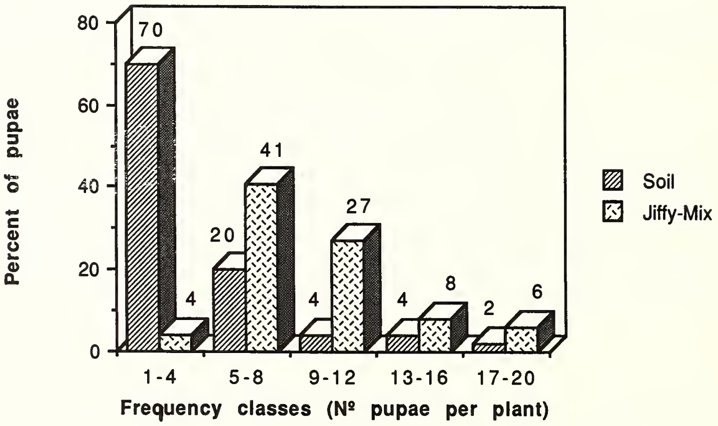

Figure 2. Frequency distributions of the numbers of pupae per Hessian fly-infested wheat seedling growing on potting soil or on peat-lite mix.

ure 2). Most plants grown on the potting soil had 1-4 or 5-8 pupae per plant (70% and 20%, respectively), but most seedlings grown on the commercial substrate had 5-8 or 9-12 pupae per plant (41% and 27%, respectively). The greater survival of the larvae on the peat-lite mix is illustrated by the fact that only two plants in potting soil had more than 17 pupae each, while six seedlings in the commercial medium had more than 17 pupae each.

Although the mean pupal sizes were similar in plants from both treatments, they were also grouped in frequency classes (Figure 3) in order to visualize possible differences among treatments. Most plants on potting soil had pupae measuring 4.1-4.5 mm, but most plants on the peat-lite mix had pupae measuring 3.6-4.0 mm.

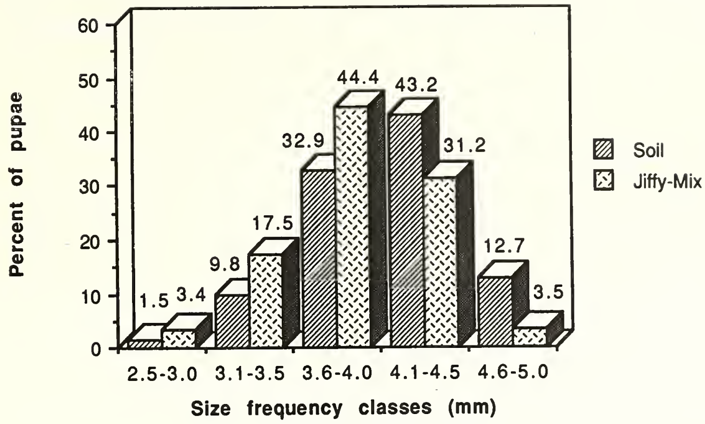

Figure 3. Frequency distributions of the size of pupae from Hessian fly-infested wheat seedlings growing on potting soil or on peat lite mix.

The increase in the number of pupae on seedlings grown on the peat-lite mix compared to the potting soil may have been due to the more stable moisture level in the growing medium. The commercial peat-lite mix required about half the time for watering the flats, since the moisture was maintained for longer periods of time. The increase in the number of pupae on this treatment may have also tended to shift the predominant pupal size towards relatively smaller pupae.

These results warrant further study. The increased production of bulk populations of HF biotypes could represent savings of as much as half the materials and space required traditionally. Also, when sifting the potting soil from infested wheat plants, a number of puparia are dislodged or crushed. The combined growing substrate, however, does not require sifting, which is replaced by trimming the seedlings 1 cm above the growing medium. Another possible direction for research is to study the effects of pupal sizes on fly emergence or on the HF male:female ratio as related to wheats with varying degrees of plant resistance to this insect pest.

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## LITERATURE CITED

Foster, J.E., J.E. Araya, G. Safranski, S.E. Cambron, and P.L. Taylor. 1988. Rearing Hessian flies in selection of wheat cultivars for fly resistance. Purdue Univ. Agr. Exp. Sta. Bull. 536, 16 pp.

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# WICKCLIFF SANDSTONE (UPPER CHESTERIAN, MISSISSIPPIAN) OF MALOTT, REVISITED

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ABSTRACT: Midway in the Buffalo Wallow Group (upper Chesterian, Mississippian) of southwestern Indiana is a minor rock unit that C.A. Malott in 1925 named the Wickcliff Sandstone. The precise stratigraphic position of this bed remained a mystery, however, until the fortuitous discovery, just south of Patoka Reservoir in southwestern Orange County, of an occurrence of the Leopold Limestone Member (Branchville Formation), a key limestone bed that closely overlies the sandstone. The Wickcliff Sandstone is not, as Malott came to think, equivalent to, or even part of, the Waltersburg Formation of the standard Chesterian section in southern Illinois. Instead, the Wickcliff is very near the top of the Branchville Formation of Indiana outcrop usage and is equivalent to a part of the Menard Limestone, identifiable tongues of which just barely extend to the Indiana outcrop area. The position of the Wickcliff Sandstone appears to be analogous to that of the "Chapman sand," a bed that is productive of oil in Daviess and McLean Counties in western Kentucky. The stratigraphic relationships outlined and the nomenclatural puzzle that they presented are another indication that the upper Chesterian section of southwestern Indiana should be regarded as a shale-dominated sequence into which tongues of sandstone extend from the eastern (outcrop) edge and into which tongues of limestone extend from the western (basin) portion. The name Wickcliff has been little used and the rock unit is not sufficiently important or extensive to require reincorporation into the Indiana formal stratigraphic nomenclature at this time.

## INTRODUCTION AND HISTORICAL REVIEW

In the standard section of Chesterian-age rocks in the Illinois Basin (Figure 1), the Waltersburg Formation directly overlies the Vienna Limestone, but in discussion of a stratigraphic section of Mississippian rocks exposed near Sulphur in southern Indiana, Malott and Esarey (1940, p. 7) made this puzzling statement: "The sandstone above the Vienna . . . is not the Waltersburg (Wickcliffe [sic])." To understand this statement, one must trace Malott's thinking on the classification and nomenclature of the upper part of the Chesterian Series in Indiana.

The Chesterian section, and specifically its upper part, was the last of the surface stratigraphic section in Indiana to be studied and classified. Malott and Thompson (1920) first identified a key limestone, the Siberia Limestone, now classified as a member. Subsequently, Malott traced the extent of this limestone and other key beds throughout Perry County on a blueprint map of limited circulation (Malott, 1923). Only one copy of this map, which represents a working stage in Malott's thinking on the nomenclature of the upper Chesterian, seems to have survived. Many of the names that he would later propose are in the legend (Figure 1; Malott, 1923). Below "a sandstone" of the explanation, the next unit mapped was the Glen Dean Limestone, which marks the top of the middle Chesterian. The trace of each of these named units was signified on this map by a unique patterned line.

Malott (Figure 1; 1925) next classified the entire upper Chesterian, indicating in discussion that within the dominantly shale sequence only the limestone and sandstone members were worthy of being named. This concept, which was in contrast with the

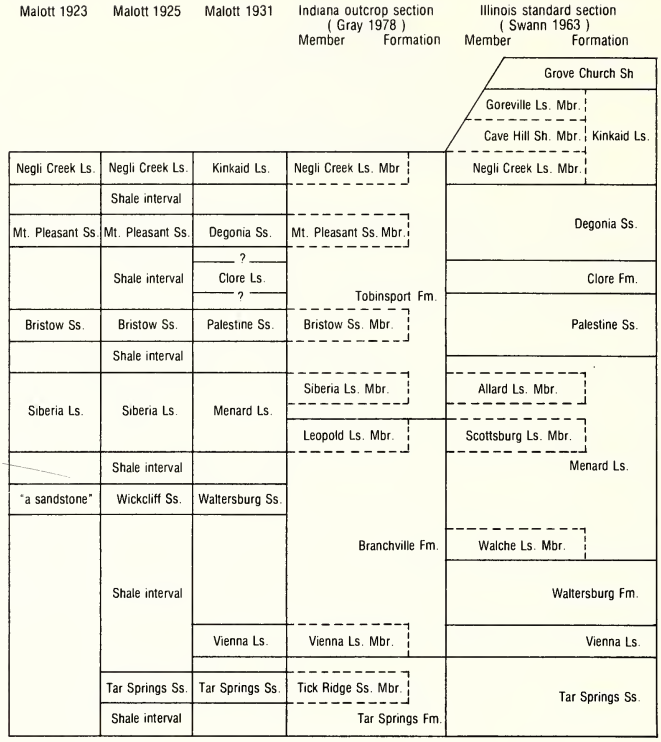

Figure 1. Chart showing evolution of nomenclature for upper Chesterian rocks in the Indiana outcrop area. The name Siberia was applied by Malott (1923, 1925) to two limestone members, the lower of which is now called the Leopold (Gray, 1978).

then-developing practices of stratigraphic nomenclature that were soon to be codified by Ashley, *et al.* (1933), has proved to be the source of many nomenclatural problems. As a final step, Malott (Figure 1; 1931) asserted correlations of the upper Chesterian units with the now standard Chesterian sequence of southern Illinois and recommended abandonment of the Indiana names. Thus, the rock unit signified on the 1923 map as "outcrop of a sandstone" below the Siberia Limestone became in 1925 the Wickcliff Sandstone, which in 1931 was transmuted into the Waltersburg. Note that most of the "shale intervals" are missing from this final list — though they were still conceptually present.

A note in passing on spelling: on modern maps, the crossroads settlement after which the sandstone is named is spelled "Wickliffe," but in Malott's (1925) initial use, and in what little subsequent geologic use there has been, the name was spelled "Wickcliff." It is so spelled in the Wilmarth (1938, pp. 2330-2331) lexicon, and that spelling is adhered to herein where reference is to the stratigraphic unit. The spelling "Wickliffe" is used where reference is to the locality.

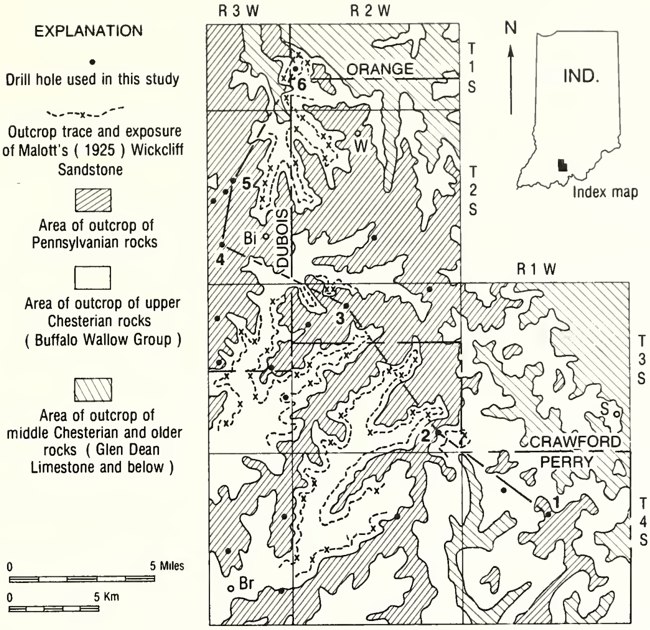
EXPLANATION
Drill hole used in this study
Outcrop trace and exposure of Malott's ( 1925 ) Wickcliff Sandstone
Area of outcrop of Pennsylvanian rocks
Area of outcrop of upper Chesterian rocks ( Buffalo Wallow Group )
Area of outcrop of middle Chesterian and older rocks ( Glen Dean Limestone and below )
0 5 Miles
0 5 Km
R 3 W
R 2 W
R 1 W
T 1 S
T 2 S
T 3 S
T 4 S
N
IND.
Index map
ORANGE
DUBOIS
CRAWFORD
PERRY
W
Bi
Br
S
1
2
3
4
5
6

Figure 2. Geologic map showing crop-line of Malott's (1925) Wickcliff Sandstone (dashed line, in part after Malott, 1923) and location of selected datum points. Numbers and line of section refer to Figure 3. Other contacts are based on Gray, Ault, and Keller, 1987. Bi, Birdseye; Br, Bristow; S, Sulphur; W, Wickliffe.

## THE STRATIGRAPHIC PROBLEM

But why was "the sandstone above the Vienna" not the Waltersburg? First, because in Malott's concept, only a relatively thin sandstone (Wickcliff of his 1925 paper) could be the Waltersburg; and second, because to be the (Wickcliff) Waltersburg, this sandstone should be "fully 60 feet [18 m] above...the Vienna" (Malott and Esarey, 1940). Malott (1925, p.127) had not specifically designated a type section for the Wickcliff, and he also questioned whether the sandstone should receive a name (Malott, 1925, p. 109). All this contributed to uncertainty that surrounded the stratigraphic identity of this member. As a result, when the upper Chesterian was restudied (Figure 1; Gray, 1978), the (Wickcliff) Waltersburg of Malott again became merely "a sandstone" somewhere in the upper part of the Branchville Formation — until a key to the stratigraphic position of this member was discovered.

South of Patoka Reservoir, in the Newton Stewart Recreation Area, about 3 miles (5 km) north and a little west of the crossroads of Wickliffe (Figure 2), is a prominent and rather extensive rimrock of sandstone that at first glance one is likely to assign to the Mansfield Formation, which is basal to the Pennsylvanian System in Indiana. The ledge is about 20 feet (6m) thick, is prominently cross-stratified, and makes bold rock cities near hill crests in the recreation area. In recent mapping (Gray, Wayne, and Wier, 1970), this ledge was assigned to the basal Pennsylvanian.

Yet, new facts intrude. While doing unrelated fieldwork in the area in 1980, Carl Rexroad and I came upon a large slab and several smaller pieces of limestone that had been excavated from a utility trench at the top of the hill near the Newton Stewart Visitor Center. The limestone does not crop out, and unfortunately the rock was not observed in place in the trench, but it certainly overlies the rimrock sandstone that had previously been held to be Mansfield. The limestone contains a Chesterian conodont fauna dominated by *Cavusgnathus unicornis* (Carl B. Rexroad, pers. comm., 1991), which, along with other indications, demonstrates that the sandstone of the rimrock ledge is Mississippian in age. Malott's Wickcliff Sandstone had been rediscovered.

## THE PRESENT STUDY

**Subsurface data.** A modest drilling program had been planned by the Indiana Geological Survey to determine the northernmost extent of some of the Chesterian stratigraphic units, and so it was obvious that a core hole in the Newton Stewart Recreation Area was essential. This became Survey Drill Hole 311 (Figure 3 and Appendix, well record A), which established the top of the Wickcliff Sandstone of the nearby outcrop as some 134 feet (40.8 m) above the Glen Dean Limestone, about as Malott (1925) had indicated. The Leopold Limestone Member, which defines the top of the Branchville Formation, is not present in the core hole, but on the adjacent hilltop it is about 160 feet (49 m) above the top of the Glen Dean Limestone, well within normal range (Gray,

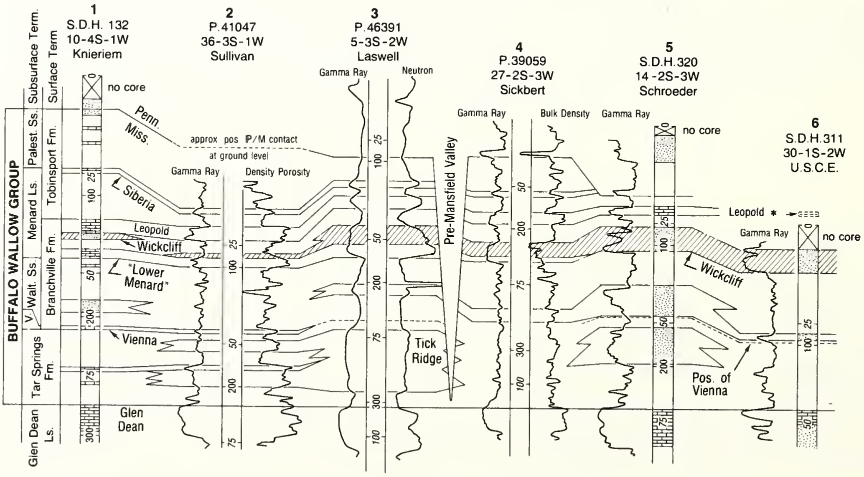

Figure 3. Selected core-hole and wire-line drilling records correlated from northeastern Perry County to southwestern Orange County, showing the stratigraphic placement of Malott's (1925) Wickcliff Sandstone within the Buffalo Wallow Group. The asterisk marks the position of the Leopold Limestone Member projected from hilltop excavation near core hole. No horizontal scale. Metric depths are shown in italics. See Figure 2 for location of wells.

1978). A second core hole, Survey Drill Hole 320 (Figure 3 and Appendix, well record B), verified the placement of the Wickcliff in respect to the Leopold and also confirmed that nearby long- abandoned limestone quarries probably were in the Siberia member of the Tobinsport Formation.

A number of commercial wire-line logs from the area were selected for further study (Table 1). These logs made possible correlation of the Wickcliff Sandstone and associated stratigraphic units to units routinely recognized in the subsurface and to Survey Drill Hole 132 (Figure 3), a key record that displays nearly all the upper Chesterian of the Indiana outcrop area. In these records, the Wickcliff Sandstone is characteristically about 20 feet (6 m) thick and is positioned just below the Leopold Limestone Member of the Branchville Formation and above the "lower Menard" of subsurface usage. Thus, the Wickcliff is stratigraphically equivalent to rocks that in the subsurface are assigned to the Menard Limestone. The Siberia Limestone Member of Indiana outcrop usage appears to correlate with the "upper Menard" of subsurface usage and thus to the Allard Member of the Illinois standard section (Figure 1).

**Type locality and type section.** Malott did not designate a type section for his Wickcliff Sandstone, but of the sections he described, only one (Malott, 1925, p. 127) suits. Its location is given as "just south of Wickcliff, along the Birdseye road and in a small creek or branch." The exact location of this section is uncertain, but for purpose of discussion, Malott's text description is recast here in the style of his other described sections:

| | Ft | (m) |
|---|---|---|
| 4. Light and olive green shales | 20 | (6.1) |
| 3. Wickcliff Sandstone, massive, cross-bedded | 35 | (10.7) |
| 2. Dark sandy and olive shales | 30 | (9.2) |
| 1. Tar Springs Sandstone, laminated, massive | 35 | (10.7) |

Within unit 4 is "a ledge of yellow limestone a foot or more in thickness" that "apparently is the one which usually occurs beneath the Siberia limestone" (Malott, 1925, p. 127). This is the Leopold of present usage. The sandstone Malott identified as Tar Springs must be within the Waltersburg and probably is the "not the Waltersburg" of Malott and Esarey (1940); at no place within the area of study is the interval between the Tick Ridge Sandstone Member of the Tar Springs Formation and the Wickcliff as short as 30 feet (9 m). Furthermore, Malott and Esarey (1940) expected to find the (Wickcliff) Waltersburg "fully 60 feet [18 m] above...the Vienna." Compare this section with the log of Survey Drill Hole 320 (Figure 3, datum point 5), which is at no great distance southwest.

**Character of the sandstone.** Following discovery of the Leopold limestone at the Newton Stewart State Recreation Area, the character of the rimrock sandstone just below it came under closer scrutiny. Where most boldly expressed, the sandstone is strongly cross-stratified in large, simple sets of planar strata that incline gently and almost uniformly to the west. The unit also is extensively marked by honeycomb weathering. Neither feature is typical of sandstones in the Mansfield Formation.

Table 1. Well records consulted in this study, showing thickness of Wickcliff Sandstone of Malott (1925) and interval from top of sandstone to top of Glen Dean Limestone. Numbers refer to correlated wire-line logs shown on Figure 3.

| County | Location | Permit | Name | Thickness | Interval | Comment | Number |
|---|---|---|---|---|---|---|---|
| Orange | NE/SW/NW 30-1S-2W | 458NP | S.D.H. 311 U.S. Corps of Engineers | 19+ ft (5.8 m) of record | 134+ ft (40.8 m) | Wickcliff at top | 6 |
| Crawford | SW/SW/NE 28-2S-2W | 46230 | Atkins No. 8 Fields | Absent | ———— | Base Penn. on Waltersburg | |
| Dubois | SW/NW/SW 14-2S-3W | 572NP | S.D.H. 320 Schroeder | 21 ft (6.4 m) | 148 ft (45.1 m) | Base Penn. on Menard, just below Siberia | 5 |
| do | SE/SE 15-2S-3W | 39059 | Anschutz No. 21 Hoffman | 19 ft (5.8 m) | 151 ft (46.1 m) | Base Penn. on Siberia/ upper Menard | |
| do | NW/NW 22-2S-3W | 39059 | Anschutz No. 2 Schnell | 20 ft (6.1 m) | 149 ft (45.5 m) | Leopold at top of record | |
| do | SE 27-2S-3W | 39059 | Anschutz No. 6 Sickbert | 16 ft (4.9 m) | 137 ft (41.8 m) | Base Penn. on Palestine | 4 |
| Crawford | NE/SE/NE 2-3S-2W | 36127 | Reynolds and Vincent No. 1 Newton | 6(?) ft (1.8 m) | 130 ft (39.7 m) | Base Penn. on Leopold/ middle Menard | |
| do | SW/NE/SE 5-3S-2W | 46391 | Atkins No. 1 Laswell | 18 ft (5.5 m) | 152 ft (46.4 m) | Base Penn. on Palestine | 3 |
| do | SE/SE/NW 7-3S-2W | 46340 | Atkins No. 1 Wright | 8(?) ft (2.4 m) | 138 ft (42.1 m) | Base Penn. on Palestine | |
| Perry | NW/SE/NW 17-3S-2W | 35679 | Reynolds and Vincent No. 1 Zehr | 17+ ft (5.2 m) | 155 ft (47.3 m) | Wickcliff at top of record | |
| do | SW/NW/NW 36-3S-2W | 41047 | Tamrack No. 9 Sullivan | 6 ft (1.8 m) | 130 ft (39.7 m) | Palestine at top of record | 2 |
| Dubois | NW/NW/NE 10-3S-3W | 12347 | Kingwood No. 1 Peak | Absent | ———— | Base Penn. on Waltersburg | |
| do | SE/SW/SW 13-3S-3W | 40338 | Loper No. 2 Critchfield | 6(?) ft (1.8 m) | 141 ft (43.0 m) | Base Penn. on Siberia/ upper Menard | |
| do | NE/NW/SE 15-3S-3W | 10811 | Kingwood No. 1 Boeckman | May be present | 135 ft (41.2 m) | Base Penn. on Menard, just below Siberia | |
| Perry | SW/SE/SE 24-3S-3W | 32588 | Par No. 1 Seufert | 6 ft (1.8 m) | 131 ft (40.0 m) | Menard, just below Siberia, at top | |

| County | Location | Permit | Name | Thickness | Interval | Comment | Number |
|---|---|---|---|---|---|---|---|
| do | SW/SE 5-4S-1W | 43558 | Citizens No. 1 Galey | 7 ft (2.1 m) | 140 ft (42.7 m) | Menard, just below Siberia, at top | |
| do | SW/SW/SW 10-4S-1W | — | S.D.H. 132 Knieriem | 5 ft (1.5 m) | 144 ft (43.9 m) | Base Penn. on Mt.Pleasant/ Degonia | 1 |
| do | NE/NE 15-4S-2W | 40026 | Turner No. 2 Ray and Flamion | 6(?) ft (1.8 m) | 134 ft (40.9 m) | Base Penn. on Palestine | |
| do | SW/SE 12-4S-3W | 621NP | Vickery No. 1 Beard | 8(?) ft (2.4 m) | 138 ft (42.1 m) | Base Penn. on Clore | |
| do | NE/NW/NE 22-4S-3W | 621NP | Vickery Nos. 1-3 Gehlhausen | 5 ft (1.5 m) | 144 ft (43.9 m) | Base Penn. on Clore | |
| do | NE/NW/SE 2524-3S-3W | 39421 | Rogers No. 1 Styline | 6(?) ft (1.8 m) | 120 ft (36.6 m) | Base Penn. on Clore | |

Traced northward along the ridge where the capping limestone was discovered, sandstone of this character disappears and is replaced, at the same topographic position, by a less continuous ledge that does not form rock cities, is chaotically cross- stratified on a smaller scale, and includes many ferruginous concretions and a few plant impressions. These features indicate that this sandstone is Pennsylvanian in age and is properly assigned to the Mansfield Formation, although the contact between the two sandstones cannot be seen. Still farther northward, the Mansfield progressively cuts out more and more of the upper Chesterian section, so that in the vicinity of Patoka Dam, about 3 miles (5 km) northwest of the core-hole site, the Mansfield rests on the Glen Dean Limestone. From there northward, rocks of the Buffalo Wallow Group are unknown along the outcrop, although the Glen Dean Limestone is widely present.

Malott (1925, p. 108) described the Wickcliff Sandstone, entirely from outcrop reconnaissance, as having a thickness of as much as "35 or 40 feet [11 or 12 m]," but these figures could not be verified. The maximum thickness observed during this study was 21 ft (6.4 m; Table 1). On outcrop, the sandstone characteristically forms shelving, overhanging, discontinuous ledges that are most prominent in ravines, where waterfalls over the ledges are common.

Within the area of its occurrence, the Wickcliff Sandstone forms, as Malott (1925, p. 109) observed, "a dependable horizon for structure determination." The median interval from the top of the Glen Dean Limestone to the top of the sandstone, as determined from the 19 datum points listed in Table 1, is 138 ft (42.1 m), very close to the figure given by Malott. Determination of sandstone thickness in these wire-line logs is subject to too great a relative error to produce reliable statistics, but it appears that the thicker sections outline a vague northwest-southeast trend, essentially from datum point 6 to datum point 3 (Figure 2). The area of thicker sandstone corresponds to an area where the Glen Dean-Wickcliff interval is thicker than normal.

**Areal distribution of the sandstone.** Geologic mapping (Figure 2) shows that the Wickcliff Sandstone crops out in two distinct areas — one between Wickliffe and Birdseye, the other south of Birdseye in the various branches of the Anderson River. The two areas are separated by a pre-Mansfield valley, now expressed by the trace of the Mississippian-Pennsylvanian unconformity. This valley trends southwestward across T2S, R2W from the outcrop area southeast of Wickliffe, where basal Mansfield rests on Glen Dean in an exposure along State Route 145 (Gray, *et al.,* 1957, pp. 28- 29), to a cluster of wells at the southeastern corner of Dubois County. In this area, the Wickcliff is missing as a consequence of pre-Mansfield erosion.

Along the Indiana outcrop south of the area mapped on Figure 2, a nearly complete section of upper Chesterian rocks is present (Gray, 1978), but neither drill-hole data nor outcrops outline additional areas of sandstone at the appropriate stratigraphic position. It seems probable that in this area the Wickcliff is missing by nondeposition. Farther south, in a section just across the Ohio River in Kentucky, Malott (1925, p. 116) described a thin sandstone that he identified as Wickcliff. This bed lies, however, too low in the section (Gray, 1978, Figure 3, section 1). Furthermore, detailed surface mapping in this part of Kentucky (Bergendahl, 1965; Crittenden and Hose, 1965) failed to find a sandstone of significant extent at the position of the Wickcliff.

In the subsurface of southern Indiana, a sandstone in the lower part of the Menard Limestone, and therefore possibly equivalent to the Wickcliff Sandstone, is known in parts of Spencer and Warrick Counties (S.J. Keller, pers. comm., 1991). A sandstone in similar position in Daviess and McLean Counties, western Kentucky, is called the "Chapman sand" by drillers (Swann,1963, pp. 38, 63). These areas of sandstone are about 40 miles (60 km) southwest of the outcrop area of the Wickcliff Sandstone and may have had a source and origin different from that of the sandstone in the outcrop area.

## CONCLUSIONS

The eastward tonguing-out of the Menard Limestone at the outcrop, along with the limited distribution of the Wickcliff Sandstone, imply a continuation of basin geometry as outlined by Swann (1963, Figure 4 and pp. 11-17). The Wickcliff may be a remnant of a ribbon or pod of Potter's (1963) classification of sandstone bodies; if so, a near approach to the paleoshoreline would not be indicated and, indeed, should not be expected from the close association of the sandstone with tongues of the Menard Limestone. The sandstone does not extend far into the subsurface and most probably represents a distal end of the Michigan River deltaic complex envisioned by Swann (1963).

Although an outline of the basic conclusions presented herein has appeared in the current compendium of Indiana stratigraphic nomenclature (Gray, 1986), it has seemed advisable to present also the analysis that supports those conclusions. The limited distribution of the Wickcliff Sandstone and the former enigma of its stratigraphic position seem sufficient to explain the infrequent past use of the name. Cited herein are almost all of its mentions. The name Wickcliff properly makes an appearance in Wilmarth (1938, pp. 2330-2331), where it is not, however, marked as a term abandoned by its originator, but rather as a name whosestatus had not been officially considered by the U.S. Geological Survey. At this juncture, despite a new and corrected understanding, there seems no point in rejuvenating the name.

## LITERATURE CITED

Ashley, G.H., M.G. Cheney, J.J. Galloway, C.N. Gould, C.J. Hares, B.F. Howell, A.I. Levorsen, H.D. Miser, J.B. Reeside, Jr., W.W. Rubey, T.W. Stanton, G.W. Stose, and W.H. Twenhofel. 1933. Classification and nomenclature of rock units. Bull. Geol. Soc. Amer. 44: 423-459.

Bergendahl, M.H. 1965. Geology of the Cloverport Quadrangle, Kentucky-Indiana, and the Kentucky part of the Cannelton Quadrangle, Scale 1:24,000. U.S. Geol. Surv. Geol. Quad. Map GQ-273.

Crittenden, M.D.,Jr. and R.K. Hose. 1965. Geology of the Rome Quadrangle in Kentucky, Scale 1:24,000. U.S. Geol. Surv. Geol. Quad. Map GQ-362.

Gray, H.H. 1978. Buffalo Wallow Group, upper Chesterian (Mississippian) of southern Indiana. Indiana Geol. Surv. Occas. Paper 25, 28 pp.

__________. 1986. Leopold Limestone Member, Branchville Formation, Mississippian System. *In:* Shaver, R.H., C.H. Ault, A.M. Burger, D.D. Carr, J.B. Droste, D.L. Eggert, H.H. Gray, D. Harper, N.R. Hasenmueller, W.A. Hasenmueller, A.S. Horowitz, H.C. Hutchinson, B.D. Keith, S.J. Keller, J.B. Patton, C.B. Rexroad, and C.E. Weir, *Compendium of Paleozoic Rock-Unit Stratigraphy in Indiana— A Revision,* pp. 76-77, Indiana Geol. Surv. Bull. 59, 203 pp.

__________, C.H. Ault, and S.J. Keller. 1987. Bedrock geologic map of Indiana, Scale 1:500,000. Indiana Geol. Surv. Misc. Map 48.

__________, T.A. Dawson, D.J. McGregor, T.G. Perry, and W.J. Wayne. 1957. Rocks associated with the Mississippian-Pennsylvanian unconformity in southwestern Indiana. Indiana Geol. Surv. Field Conf. Guidebook 9, 42 pp.

__________, W.J. Wayne, and C.E. Wier. 1970. Geologic map of the 1° by 2° Vincennes Quadrangle and parts of adjoining quadrangles, Indiana and Illinois, Scale 1:250,000. Indiana Geol. Surv. Regional Geol. Map 3.

Malott, C.A. 1923. Geologic map of Perry County, Indiana, showing.....readily traceable and recognizable members of the Chester Series..... (privately issued, blueprint copy).

__________. 1925. The upper Chester of Indiana. Proc. Indiana Acad. Sci. 34: 103-132.

__________. 1931. Geologic structure in the Indian and Trinity Springs locality, Martin County, Indiana. Proc. Indiana Acad. Sci. 40: 217-231.

__________ and R.E. Esarey. 1940. Outcrop of the Chester Series of southern Indiana. Indiana-Kentucky Geol. Soc. Guidebook, May 18, 1940, 9 pp. (mimeographed).

___________ and J.D. Thompson, Jr. 1920. The stratigraphy of the Chester Series of southern Indiana. Science 51: 521-522 (abstr.).

Potter, P.E. 1963. Late Paleozoic sandstones of the Illinois Basin. Illinois State Geol. Surv. Rep. Invest. 217, 92 pp.

Swann, D.H. 1963. Classification of Genevievian and Chesterian (Late Mississippian) rocks of Illinois. Illinois State Geol. Surv. Rep. Invest. 216, 91 pp.

Wilmarth, W.G. 1938. Lexicon of geologic names of the United States. U.S. Geol. Surv. Bull. 896, 2396 pp.

## APPENDIX

A. Description of upper part of core from Survey Drill Hole 311, U.S. Corps of Engineers, Newton Stewart State Recreation Area, NE¼, SW¼, NW¼, Sec. 30, T1S, R2W, Orange County, Indiana. Datum point 6 on Figures 2 and 3. Surface altitude 705 ft (215 m). Summarized from description by Henry H. Gray, December 1981-January 1982. Metric conversions in parentheses. Conodont identifications by Carl B. Rexroad.

| Description | Thickness | Depth |
|---|---|---|
| No record. Core starts at 20 feet (6.1 m) | 20.0<br>(6.1) | 20.0<br>(6.1) |

## *MISSISSIPPIAN SYSTEM*

### *Buffalo Wallow Group* - 133.7 ft (40.8 m) cored

### *Branchville Formation* - 78.5 ft (24.0 m) cored

| | | |
|---|---|---|
| Sandstone, light yellow-brown to light gray; indistinct even thin to medium strata, mostly in small tabular cross-sets; fine to medium sand; scattered light gray clay chips in several zones; friable. *Wickcliff Sandstone* of Malott (1925) | 19.0<br>(5.8) | 39.0<br>(11.9) |
| Mudstone and shale, mostly medium gray; some interstratified siltstone. Much core loss in this unit | 25.5<br>(7.8) | 64.5<br>(19.7) |
| Shale, dark gray; distinct even very thin strata; unit is uniform and distinctive on gamma-ray log | 26.6<br>(8.1) | 91.1<br>(27.8) |
| Rubble zone; contorted shale, ironstone, and sandstone chips | 0.3<br>(0.1) | 91.4<br>(27.9) |
| Sandstone, light gray; few calcareous zones near top | 6.6<br>(2.0) | 98.0<br>(29.9) |
| Rubble zone; contorted ankerite nodules in medium gray silt matrix.Probable position of *Vienna Limestone Member* | 0.5<br>(0.2) | 98.5<br>(30.1) |

### *Tar Springs Formation* - 55.2 ft (16.8 m)

| | | |
|---|---|---|
| Mudstone and siltstone, medium green-gray | 7.0<br>(2.1) | 105.5<br>(32.2) |
| Shale, very thinly interstratified with siltstone and very fine-grained sandstone; medium to dark gray | 13.5<br>(4.1) | 119.0<br>(36.3) |
| Siltstone and mudstone; calcareous, medium green-gray; bryozoans abundant throughout. *Cavusgnathus* and *Kladognathus* rare in basal 13.1 ft (4.0 m) | 19.1<br>(5.8) | 138.1<br>(42.1) |

| | | |
|---|---|---|
| Mudstone-limestone, medium green-gray; a hash of calcareous fossils in a mud matrix. *Kladognathus* rare | 1.6<br>(0.5) | 139.7<br>(42.6) |
| Shale, dark gray; distinct even very thin strata | 14.0<br>(4.3) | 153.7<br>(46.9) |
| *Stephensport Group* | | |
| *Glen Dean Limestone* | | |

B. Description of upper part of core from Survey Drill Hole 320, property of Walter and Marie Schroeder, SW$^{1}/_{4}$, NW$^{1}/_{4}$, SW$^{1}/_{4}$, Sec. 14, T2S, R3W, Dubois County, Indiana. Datum point 5 on Figures 2 and 3. Surface altitude 677 ft (206 m). Summarized from description by Henry H. Gray, February-April 1983. Metric conversions in parentheses. Conodont identifications by Carl B. Rexroad.

| Description | Thickness | Depth |
|---|---|---|
| No record. Core begins at 7.0 ft (2.1 m) | 7.0<br>(2.1) | 7.0<br>(2.1) |
| *PENNSYLVANIAN SYSTEM* | | |
| *Raccoon Creek Group* | | |
| *Mansfield Formation* - 51.4 ft (15.7 m) cored | | |
| Sandstone, light gray; in part thinly interstratified with medium gray shale; scattered carbonaceous material and mica flakes throughout | 21.9<br>(6.7) | 28.9<br>(8.8) |
| Shale, coaly, medium to dark gray | 0.5<br>(0.2) | 29.4<br>(9.0) |
| Claystone, medium green-gray | 3.6<br>(1.1) | 33.0<br>(10.1) |
| Shale, dark gray; even very thin strata and minor interstratified siltstone | 20.2<br>(6.1) | 53.2<br>(16.2) |

| | | |
|---|---|---|
| Sandstone and shale, irregularly interstratified; in part cemented by large luster-mottled crystals of calcite; toward base contains scattered well-rounded pebbles of limestone and chert as large as 2 cm | 3.3<br>(1.0) | 56.5<br>(17.2) |
| Limestone and shale interstratified; coarse to medium grainstone containing rounded clasts as large as 5 cm, and dark gray shale. Contains *Adetognathus lautus* and *Idioprioniodus conjunctus,* on the basis of which this and the unit above have been assigned to the Pennsylvanian System | 1.9<br>(0.6) | 58.4<br>(17.8) |

## *MISSISSIPPIAN SYSTEM*

### *Buffalo Wallow Group* - 174.8 ft (53.3 m)

### *Tobinsport Formation* - 9.7 ft (3.0 m)

| | | |
|---|---|---|
| Shale and sandstone interstratified, medium gray; even to wavy very thin strata | 9.7<br>(3.0) | 68.1<br>(20.8) |

### *Branchville Formation* - 91.2 ft (27.8 m)

#### *Leopold Limestone Member* - 6.9 ft (2.1 m)

| | | |
|---|---|---|
| Dolomite, micritic, light yellow brown; in part a breccia with a matrix of light green-gray mudstone. *Cavusgnathus* and *Kladognathus* rare in basal 2.1 ft (0.6 m) | 6.9<br>(2.1) | 75.0<br>(22.9) |

#### *Unassigned as to member* - 84.1 ft (25.6 m)

| | | |
|---|---|---|
| Shale and siltstone interstratified, medium gray; distinct even to contorted thin strata | 9.9<br>(3.0) | 84.9<br>(25.9) |
| Sandstone, fine- to very fine-grained, in part interstratified with shale; light to medium gray. *Wickcliff Sandstone* of Malott (1925) | 21.0<br>(6.4) | 105.9<br>(32.3) |
| Shale and mudstone; dark gray to medium green-gray | 27.8<br>(8.5) | 133.7<br>(40.8) |

| | | |
|---|---|---|
| Sandstone, fine- to very fine-grained; light gray, increasingly interstratified downward with dark gray shale | 25.4<br>(7.7) | 159.1<br>(48.5) |
| *Vienna Limestone Member* - 0.2 ft (0.1 m) | | |
| Limestone, argillaceous, medium yellow- brown; abundant coarsely crystalline fossil fragments, including bryozoans and brachiopods, in an argillaceous matrix. *Cavusgnathus* and *Kladognathus* rare | 0.2<br>(0.1) | 159.3<br>(48.6) |
| *Tar Springs Formation* - 73.9 ft (22.5 m) | | |
| *Unassigned as to member* - 8.9 ft (2.7 m) | | |
| Sandstone and shale interstratified, medium to light gray | 8.9<br>(2.7) | 168.2<br>(51.3) |
| *Tick Ridge Sandstone Member* - 30.7 ft (9.4 m) | | |
| Sandstone, in part interstratified with shale, light gray | 30.7<br>(9.4) | 198.9<br>(60.7) |
| *Unassigned as to member* - 34.3 ft (10.5 m) | | |
| Shale and siltstone interstratified, medium gray; two minor beds of sandstone | 29.9<br>(9.1) | 228.8<br>(69.8) |
| Limestone, intramicrudite(?); abundant irregular clasts as much as 1.5 cm across are light yellow-brown, earthy, dolomitic, in a medium green-gray matrix. *Cavusgnathus altus, Hindeodus cristulus,* and *Lochriea commutatus* present | 0.6<br>(0.2) | 229.4<br>(70.0) |
| Shale, calcareous, medium gray; abundant fenestrate bryozoans, two *Archimedes* observed. *Cavusgnathus altus, C. unicornis,Kladognathus primus,* and *Hindeodus cristulus* common | 3.8<br>(1.2) | 233.2<br>(71.2) |

*Stephensport Group*

*Glen Dean Limestone*

C. For a summary description of Survey Drill Hole 132, datum point 1 on Figures 2 and 3, see Gray, 1978, Appendix 2.

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# MANSFIELD NATURAL BRIDGE, PARKE COUNTY: REQUIEM FOR A VANISHED INDIANA LANDMARK

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ABSTRACT: Mansfield Natural Bridge, a bedrock arch developed in Pennsylvanian age Mansfield Formation sandstone adjacent to Big Raccoon Creek, eastern Parke County, Indiana, was destroyed during quarry operations sometime between 1950 and 1955. This feature apparently was one of the largest natural bridges in the Ohio Valley region, perhaps exceeded in size only by the Powell County, Kentucky, sandstone arch. Plans to construct a flood control dam and reservoir at the natural bridge site, as well as interference with ongoing quarry operations, apparently were primary factors that led to removal of this significant landform; today, environmental concerns would not permit such action. Early descriptions of the arch and geological explanations of the origin are limited and vague. Historical background information on the arch, especially through a photographic record, is presented in this paper; a better theory for the geological origin is provided; and the reason why this natural bridge was the sole representative of this landform type along Big Raccoon Creek is explained.

## THE SEARCH

Thanksgiving Saturday, 1990, dawned sunny, bright, and unseasonably warm. Some autumn color remained in the woods, and it seemed an ideal day to visit an Indiana natural feature, before known to me only casually. I had seen brief descriptions and photographs by Dryer (1913) and Dow (1938) of Mansfield Natural Bridge, one of two significant sandstone natural arches in Indiana, and reportedly one of the largest landforms of this type in the Ohio Valley region. I was familiar with the other Indiana natural bridge of this genre, the so-called Portland Arch in Fountain County, south of Attica. This latter arch, after all, is near Purdue; I had visited there with students on many field trips, the geological origin seemed clearly evident, and it always was pleasant to hike trails in the rock canyon cut by Bear Creek. The Mansfield feature, however, was twice as distant — nearly 60 miles from campus — the described location was somewhat uncertain, and the site never had been a field excursion target.

As my initial trip was spontaneous, I really had not done a proper literature search. Thus, with no location description other than that the arch was "about two miles northeast of the town of Mansfield ..." (Dow, 1938, p. 56), but with trusty topographic map in hand, I sallied forth and picked what experience indicated was a likely location; this was a streamlined, clearly bedrock-cored knob south of Big Raccoon Creek, and the requisite distance and direction from Mansfield (Figure 1). There, luck intervened, for I met Mr. Raymond Martin at his farm residence. Mr. Martin knew of the natural bridge — or, rather, as it developed, the former natural bridge — for it had been located on his original family homestead, a property settled in 1819. However, the actual site had been north of the creek, nearly a mile distant from where we stood! The topographic map provided no solace, but on subsequent trips, with the help of Mr. Martin and other longtime local residents, I have documented fairly well the timing of and reasons for destruction of this natural bridge. Herein also is proffered a probable geological explanation of the origin of this solitary sandstone arch; this explanation is better, at least, than

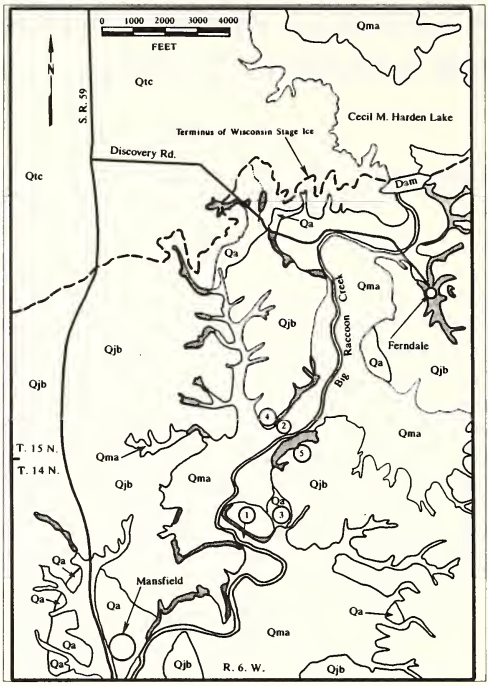

Figure 1. Location map and generalized geology of the Mansfield area, Parke County (geology modified from Hutchison, 1976): 1 = "Mansfield" dam site; 2 = "Ferndale" dam site; 3 = Martin Farm; 4 = former site of Mansfield Natural Bridge; and 5 = "The Zoo". Shaded pattern is bedrock exposure, mostly Mansfield Formation, but some Ste. Genevieve Limestone is exposed near Ferndale: Qjb = Butlerville Till Member, Jessup Formation (Illinoian ?); and Qtc = Center Grove Till Member, Trafalgar Formation (Wisconsinan). Dashed line is approximate terminus of Wisconsin stage ice: Qa = Quaternary alluvial terrace deposits; and Qma = modern alluvium.

the vague, nebulous ideas suggested in the limited earlier references to this phenomenon.

## PREVIOUS RECORDS

Richard Owen (1862, pp. 165-167) and other early geologists apparently either did not see, or failed to record, the natural bridge. Hopkins (1896, pp. 239-240) saw the arch, but makes only a brief comment about the feature, and gave a slightly incorrect location. I now know the arch was immediately adjacent and parallel to a gravel road along Big Raccoon Creek, in the SW$^{1}/_{4}$, SW$^{1}/_{4}$, Sec. 33, T15N, R6W, Union Township, Parke County (Mansfield 7$^{1}/_{2}$' quadrangle).

I then turned to the classic work on natural bridges of North America (Cleland, 1910). Cleland catalogs the "Bridge at Attica, Indiana" but, curiously, makes no mention of the Mansfield feature.

The first physical description of the arch was by Dryer (1913) in a brief paragraph that comprises Part III of his famous Wabash Studies. Dryer pictures this "Parke County

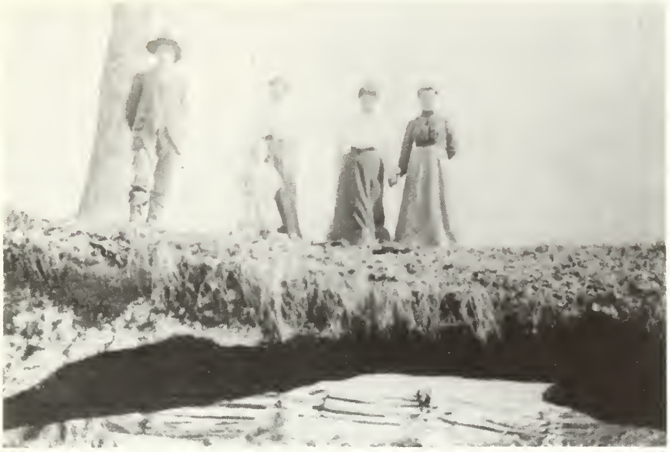

Figure 2. Mansfield Natural Arch, ca. 1904-1905, looking headward up the ravine. The split rail fence was emplaced to prevent horses from wandering onto the road, positioned about where picture was taken. Members of Martin family (left to right) on the arch: Robert Faris Martin; Albert Harney (b. 1902, son of Scott Harney and Dora Martin); Nora Martin Keyt (twin of Dora Martin and Albert's aunt); and twins, Edith and Ethel Martin (d. 1906, thus defining approximate date of photograph). Photo courtesy of Raymond Martin.

Natural Bridge" but says only that: "A small tributary of Raccoon Creek has cut a ravine in the Mansfield sandstone bluff and originally fell over a ledge about six feet high. A joint plain [sic] 20 feet back from the brink of the fall permitted the stream to descend and work its way under the stratum. The result is a natural bridge 60 feet long, 20 feet wide, 2 feet thick in the middle, with a span of 30 feet and a clear height of 6 feet underneath." (Dryer, 1913, pp. 212-213)

Dryer's photograph unfortunately is poor in quality and is a summer scene with foliage obscuring some of the arch. I have succeeded in obtaining a photograph (Figure 2) that shows part of the Martin family standing on the arch (ca. 1904-1905); at that time, a wagon could be driven from the roadway directly onto the right abutment of the natural bridge. The split-rail fence, uphill behind the arch, was erected to keep horses from straying onto the road.

The next literature reference to the bridge was by Dow (1938, pp. 56-57), who gave these measurements: inside length of span, about 54 feet; width, approximately 22 feet; height, 9 feet. These dimensions are consonant with those given by Dryer. One of Dow's pictures (Figure 3), taken in the absence of leafy vegetation, is far more revealing than Dryer's summertime photograph. Remains of the split rail fence, seen in the 1904-1905 photograph, still are evident.

The late Charles Bieber (1963, p. 181), searching for potential state park sites in the sandstone country of western Indiana, noted that the "Natural Bridge" was "destroyed by quarrying about 1955" and had been formed by "unusual stream erosion along joints in cross-bedded facies". Although Bieber's statements were more informative than anything before, I still was unsatisfied and determined to do better.

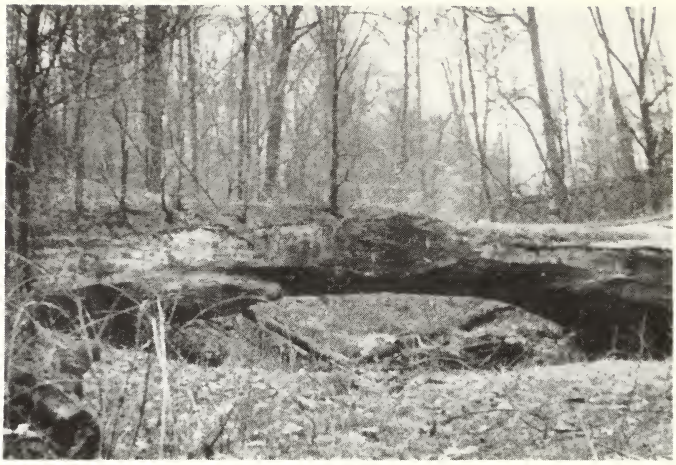

Figure 3. The arch as photographed by Dow, probably in autumn, 1937 or early 1938. Broken remains of the split rail fence are visible behind the arch.

## GEOLOGIC SETTING

Early reports by Hobbs (1872) and Hopkins (1896) primarily were concerned with the coal and building stone resources of the Mansfield area, and only Hopkins (1896, p. 212) has an accompanying geologic map. The only recent substantive publication is by Hutchison (1976). This study also places emphasis on potential for coal extraction, but the report has a detailed stratigraphy of the area as well as a very accurate, colored geologic map of the Mansfield and Catlin quadrangles.

It suffices to summarize the geology by noting that the area along Big Raccoon Creek is underlain by a sequence of Mississippian age carbonates (Ste. Genevieve Formation), unconformably overlain by Pennsylvanian sandstones and shales, primarily of the Mansfield Formation. The latter apparently was deposited in a paleochannel (Montclair Valley and tributaries) cut into the carbonates (Hutchison, 1976, p. 14). The result is relatively sparse exposures of the carbonates, except in a deep, probably karstic valley that exits at Ferndale, and around the shoreline of Cecil B. Harden Lake; the karst character of the carbonates was well-displayed in excavations at the time of dam construction. Present Big Raccoon Creek tends to follow the line of part of the old Montclair paleovalley across the area; hence, bluff-like exposures of brownish-buff, well-jointed, massive to cross-bedded Mansfield Formation sandstones are common downstream from the dam. These exposures are best on the north valley wall, where quarrying of dimension (block) stone commenced a century ago. It was during a later phase of sandstone quarrying that the natural bridge was destroyed.

Running across the upland, along a general east-west line through the dam at Cecil Harden lake, is the terminus of Wisconsin glacial ice in the region (Figure 1). This position is not marked by prominent terminal moraine; rather, the boundary is merely a zone of rolling, dissected topography. Uplands farther south are mantled with varying thicknesses of Illinoian (?) till, loess, and sand dunes.

At the Wisconsin maximum, however, sediment-bearing glacial meltwaters must have streamed in abundance down Big Raccoon Creek valley from the ice front; this left thick, extensive valley train outwash deposits. It is these deposits which determined the final location of the Mansfield Dam, and the meltwaters likely were responsible for forming the natural bridge.

## THE DESTRUCTION

Planning for a flood control structure in Raccoon Creek valley commenced with an authorization act by the U.S. Congress in June, 1938. A preliminary site was picked at that time, based on field surveys and design studies, just upstream from Mansfield village (Figure 1). After major floods in 1947 and 1950, interest in flood control was renewed. Reconnaissance showed that the original Mansfield site was unsuitable for emplacement of the left abutment, which was on sand and gravel (U.S. Army Corps of Engineers, 1956). A new site farther upstream (river mile 30.1 or "Ferndale" site) then was considered, but after study this site was deemed equally unsuitable; sandstone rock was available in the right abutment, but foundation borings elsewhere indicated a flood plain underlain by "pervious materials" (outwash sands and gravels) and "no continuous rock shelf ... at reasonable depth in either abutment or across the flood plain...". The site finally selected, 2.3 river miles farther upstream ("Seward" site, river mile 32.4), had "rock ... available in the right abutment for foundation of the outlet works", and "... the left abutment ridge has some rock near the proper elevation for the base of the spillway cut". Construction started in October, 1956, and the dam was completed in August, 1960.

Map measurement of river miles confirms that the "Ferndale" site was almost exactly at or only a few tens of feet downstream from Mansfield Natural Bridge. In fact, it was this latter feature, and adjacent sandstone bluffs, that would be the right abutment rock mentioned in the Corps of Engineers report. Obviously, at that time, it seemed that dam emplacement would either destroy or flood the natural bridge. Too, the early 1950's were a renewed time in Indiana for extraction of both limestone and sandstone blocks, much used after recutting for facing stone in residences, shopping centers, and small, free-standing professional buildings. Old quarries reopened, and new quarries sprang up like flies. Thus, at or about this time, sandstone quarrying renewed at Mansfield, including the bluff at the natural bridge. None of these sandstone quarries likely were very profitable; the stone color was drab and inconsistent, the rock slaked readily, and the early reports dwell extensively on spalling problems caused by "blisters" (small ironstone concretions). The sale value of stone in Mansfield Natural Bridge probably did not greatly exceed $25.00!

I have not been able to determine exactly when or by whom the quarrying was done, but local consensus says that the stone was cut, loaded on flatcars at a railroad spur which then extended from Rockville to Mansfield, and taken to Chicago where (presumably) the blocks were cut and sold as facing stone. The photograph (Figure 4) is from the quarry opened behind the natural bridge (perhaps photographed from the bridge itself?). Local recollection also has it that the arch was "just in the way of quarrying and, after all, the dam and lake would destroy it anyway". This idea is reiterated in the recently published history of Union Township (Parke County Historical Society, 1989). The quarry, as seen today, is shown in Figure 5. C.L. Reeves, owner of the Mansfield grist mill, died in July, 1956; by then the natural bridge was gone, to his great distress. Other veteran local residents also profess unhappiness with the act, though some of them worked in the quarry and may have been accessories in destruction of the arch! One still senses a certain uneasiness, reluctance, and "memory loss" among the locals when the

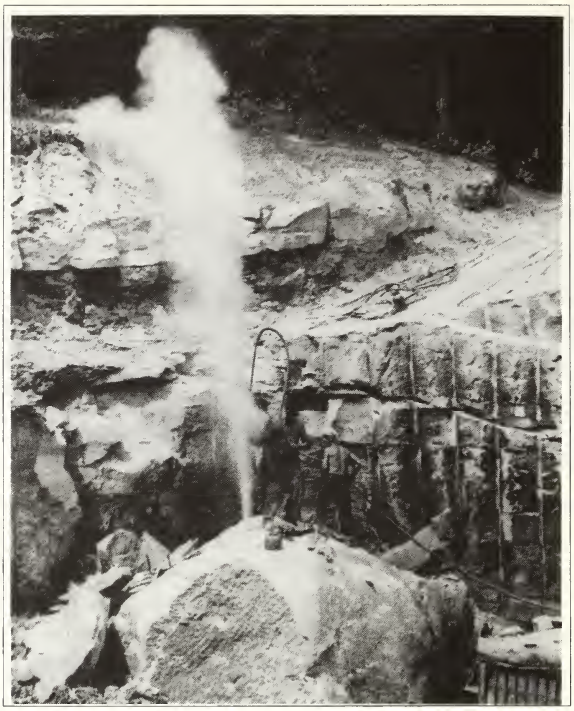

Figure 4. Sandstone quarry in operation at the natural arch. Date is unknown, but likely from the late 1940's or early 1950's. The arch was removed during quarrying; picture may have been taken from left abutment of arch prior to removal. Photo courtesy of Mr. Art Taylor.

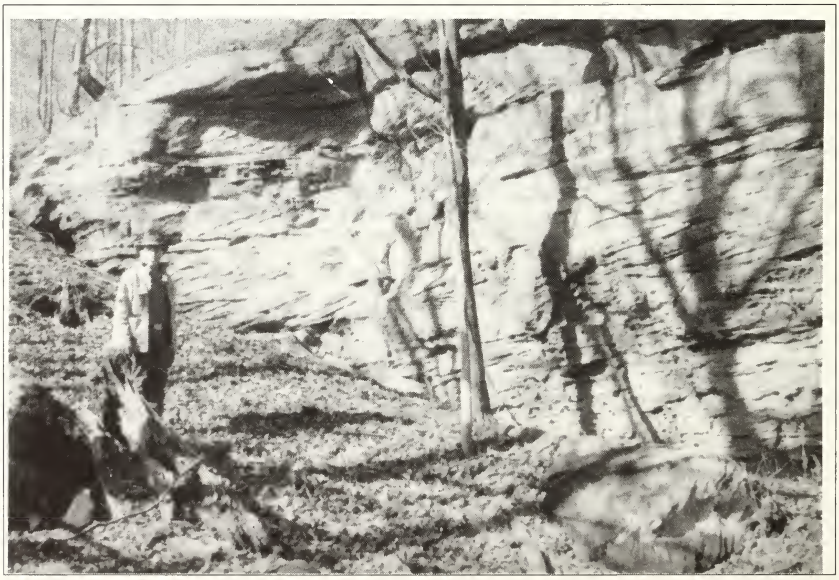

Figure 5. The quarry in November, 1990. Remains of left abutment of natural bridge immediately left of standing figure (Dr. W.J. Zinsmeister). Drill marks still visible on old quarry face at right.

natural bridge is mentioned, as if a common, lingering guilt remains.

All that is assured is that the bridge was removed after the 1950 flood and before July, 1956. Bieber's 1955 date may be correct, though H.H. Gray (pers. comm.) says that the natural bridge and rail spur were gone, and the quarry abandoned, when he was there in the late summer of 1954. Today, of course, no such act would occur; the requirement for environmental impact statements and howls of outraged preservationists assuredly would prevent quarrying. In the early 1950's, however, who could know that the then-favored "Ferndale" site would be unsuitable and that the dam actually would be built farther upstream, so that flooding or destruction of the natural arch never would have occurred?

## GEOLOGIC ORIGIN

No other natural bridges are known in the Mansfield sandstone along Big Raccoon Creek. Bluff exposures are common, and locally there is some evidence of evulsion at cliff bases. Only at one site is there any evidence of spring water emergence, thus generally excluding seasonal freeze-thaw as a major factor promoting undercutting of the bluffs.

The best clue to origin of the natural arch comes from examining a minor, wet-weather ravine almost directly across Big Raccoon Creek, only about 750 feet laterally from the former natural bridge. This unnamed ravine, locally called "The Zoo", is marked in the headward areas by a U-shaped, upland valley in Illinoian (?) till; on encountering an outcropping sandstone ledge, the ravine abruptly turns, follows a master joint face in the rock, and cuts a short but spectacular gorge at about a 45° angle to the upstream course. Below this rock gorge, the stream resumes downhill flow in a direction essentially parallel to the course held above the gorge. A minor waterfall probably existed here in the past, but only an insignificant knickpoint remains.

I speculate that the ravine holding the former natural bridge essentially was a mirror image of The Zoo. The arch was never part of a waterfall ledge, later hollowed out and cut through at the base by some vague process as recounted by Dryer (1913) and Dow (1938). The base of Mansfield Natural Bridge, according to the topographic map, was at about 600 feet elevation, and almost directly abutted the Big Raccoon Creek floodplain. Conversely, at The Zoo, the base of the exposed sandstone ledge is between 630 and 640 feet, and is some distance laterally removed from the floodplain. Therefore, I suggest that the arch was "holed through" by glacial floodwaters, which perhaps impinged repeatedly against the side and base of the former rock "spine" adjacent to the joint-controlled ravine channel. The Zoo ravine was not similarly impacted, for it was 30 or more feet higher, and far distant from any contact between meltwaters coursing down Big Raccoon valley and the base of the local rock bluff.

This explanation always will be suspect; after all, restoring a vanished landmark is somewhat akin to putting an ear to a railroad track to determine how many boxcars were in the last train. However, the two ravines discussed are the only places along the creek where there seems to be juxtaposition of a tributary drainage line, a sandstone outcrop, and a master joint. At Mansfield Natural Bridge, positive proof has been gone for more than 35 years. If not for the fortunate preservation of The Zoo, it is unlikely I could provide what I believe is a better, more rational, explanation of the origin of Mansfield Natural Bridge than occurred to earlier workers.

## ACKNOWLEDGMENTS

The author is greatly indebted to local residents of the Mansfield area, especially Mr. and Mrs. Raymond Martin and Mr. and Mrs. Art Taylor, for providing information and sharing their photographic records. Mr. Gordon Prescott aided in salvaging ancient documents from the Louisville District Office of the Corps of Engineers. Dr. Steve Kenaga, Dr. Ken Coles, and Dr. William Zinsmeister were companions and helpmates in the field.

## LITERATURE CITED

Bieber, C.L. 1963. The relation of the changing facies of the Mansfield Formation to possible park sites in western Indiana. Proc. Indiana Acad. Sci. 72: 177-181.

Dow, K.W. 1938. Natural bridges in the Mansfield Formation of Indiana. Papers Michigan Acad. Sci. Arts Lett. 24: 52-57.

Cleland, H.F. 1910. North American natural bridges, with a discussion of their origin. Bull. Geol. Soc. Amer. 21: 313- 338.

Corps of Engineers, U.S. Army. 1956. General design memorandum Mansfield Reservoir Raccoon Creek, tributary of Wabash River, Ohio River Basin, Indiana. Louisville, Kentucky, District Office, Design Memorandum 2: 5-12.

Dryer, C.R. 1913. Wabash studies, part III. A natural bridge in Parke County, Indiana. Proc. Indiana Acad. Sci., pp. 212- 213.

Hobbs, B.C. 1872. Report on geological survey of Parke County. *In:* E.T. Cox (Ed.), *3rd and 4th Annual Report, Geological Survey of Indiana made during the years 1871 and 1872,* pp. 341-384, Bright Printing, Indianapolis, Indiana, 488 pp.

Hopkins, T.C. 1896. The Carboniferous sandstones of western Indiana. Indiana Dep. Geol. Natur. Res. Annu. Rep. 20: 189- 327.

Hutchison, H.C. 1976. Geology of the Catlin-Mansfield area, Parke and Putnam counties, Indiana. Indiana Geol. Survey Bull. 54, 57 pp.

Owen, R. 1862. Report of a geological reconnaissance of Indiana, made during the years 1859 and 1860. H.H. Dodd and Co., Indianapolis, Indiana, 365 pp.

Parke County Historical Society. 1989. Union Township. *In: History and families — Parke County, Indiana,* pp. 82-83, Turner Publ. Co., Paducah, Kentucky, 392 pp.

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# THE AGROCLIMATOLOGY OF A MOISTURE STRESS INDEX AND AVERAGE CORN (*ZEA MAYS* L.) YIELDS IN TIPPECANOE COUNTY, INDIANA, 1961-1991

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ABSTRACT: Weather is the most important uncontrolled variable in crop production. Yet, its effect on crop yield is difficult to quantify in field environments where agricultural technology continually acts to increase yield potential. A single moisture stress index and a technology trend variable were used to estimate the weather effects on average county corn (*Zea mays L.*) yields, and then the climatology of that index for Tippecanoe County, Indiana, was prepared based on the 1961-1991 record. The ratios of actual evapotranspiration to potential evapotranspiration (ET/PET) were computed on a daily basis and summed to obtain moisture stress indices for three periods — 120, 90, and 37 days — of corn growth and development, each bracketing the date of corn silking. Two models, a 37-day stress index with a linear technology or trend variable and a 90-day stress index with the same technology variable plus a weather-technology interaction term, had adjusted R-squares of 0.68 and root MSEs of 0.81 t $ha^{-1}$. In the 1961-1991 period, the 37-day stress was most severe in 1991, but the full-season (120-day) and 90-day stresses were most severe in 1988. Climatological frequencies of the moisture stress indices for each of the three critical periods were highly negatively skewed, indicating a much greater probability for "favorable corn weather" than for severe moisture stress in Tippecanoe County. The climatological probability of having a 37-day stress index of 34 or greater (little or no stress) is 50%. With 1992 technology and a 37-day stress index of 34, the average corn yield for Tippecanoe County is predicted at 9.3 t $ha^{-1}$ (149 bu $a^{-1}$).

## INTRODUCTION

Weather is the most important uncontrolled variable in crop production, but its effect on crop yields is difficult to quantify in field environments where agricultural technology continually acts to increase yield potential. Efforts to evaluate the weather effects on crop development, growth, and final yield have ranged from complex biophysical simulation models to multiple regression models using many variables (Acock and Acock, 1991). The principal weather variables affecting crop growth and final yield are solar radiation, temperature, and soil moisture. All three of these variables are important, but in the U.S. Corn Belt, soil moisture is the most variable and therefore most often the major limiting factor in determining crop yields. While agricultural technology has continued to increase corn (*Zea mays* L.) yield potential, the actual yields in Indiana are still occasionally severely reduced by moisture stress, as observed in Tippecanoe County in 1983, 1988, and 1991. To quantify the weather effects on corn growth and final yields and to simplify the climatological description of "favorable corn weather", a single soil moisture stress index was used in which the daily soil water supply and the atmospheric evaporative demand on the corn crop were considered. The soil moisture stress index was defined as the sum of the daily ratios of the computed actual corn evapotranspiration to the potential evapotranspiration (ET/PET) over a given phenological period.

Whether one calculates a moisture stress variable or uses just rainfall and temperature data to correlate with corn yields, the timing of the moisture stress or rainfall with regard to corn development — corn phenology — is important in assessing weather effects on final grain yields. Even in studies in which corn yields were correlated with weather variables summed over non-phenological periods, e.g., monthly total rainfall and mean temperatures, the weather during July, in which corn silking usually occurs, has proven to be the most important predictor of State average corn yields in the U.S. Corn Belt (Thompson, 1969). Shaw (1977) summarized the experimental work of several researchers to show that moisture stress during the late vegetative stage of corn through silking had the greatest effect on final yields. However, Dale (1948), using Story County, Iowa, average corn yields, and Changnon and Neill (1968), using corn yields from 60 farms in central Illinois, found that 3-week rainfall totals centered 4 to 6 weeks before silking and again 2 weeks after silking were more highly correlated with final corn yields than was rainfall during the time of corn tasseling and silking. Agronomically, corn growth curves show rapid, almost linear, dry weight increases from 4 weeks before silking to 6 weeks after (Hanway and Russell, 1969). Stuff, *et al.* (1979, Figures 13 and 14) found that vegetative corn growth rates peaked 2 weeks before and 2 weeks after silking and that grain growth rates peaked two weeks after silking. In these periods, corn plant or grain dry weight increased an average of more than 300 kg $ha^{-1}$ $day^{-1}$. Since the ear is being differentiated about 4-6 weeks before silking (Sass and Loeffel, 1959), it is reasonable to expect that moisture stress occurring any time in the period from 6 weeks before to 6 weeks after silking can reduce corn yields. Dale and Hodges (1975) found that a daily energy-moisture stress variable, summed over the period from 6 weeks before silking to 6 weeks after silking, and the amount of nitrogen (N) applied to corn were associated with 76 percent of the variance in the Tippecanoe County average corn yields, 1954-1974.

In correlating corn yield with an unweighted sum of a daily moisture stress variable over any crop calendar period, the stress on any day in the summation period was assumed to have an equal effect on final grain yield. For estimating the economic feasibility of irrigating corn in Indiana, Paisarnuchapong (1981) correlated ($R = 0.74$) county corn yields with a moisture stress index summed over the entire corn growing season of 120 days. This period extended from planting (averaging 69 days before silking) to grain maturity about 50 days after silking. Mach and Dale (1983) correlated experimental plot corn yields with fertilizer nitrogen (N) and an energy-crop growth (ECG) variable summed over various phenological periods. The ECG is a product of the daily ET/PET ratio, the solar radiation intercepted by the corn leaf area (SR*FLAI), and a temperature function. They found the summation of ECG over a 90-day period, 39 days before to 50 days after silking, provided higher correlation with experimental plot corn yields than did ECG summations over other periods examined. Featherstone, *et al.* (1991) also used a 90-day summation of a moisture stress variable (1-ET/PET) to account for the weather influence in an economic study of corn yields from alternative tillage systems on 78 farm sites in Wabash County in 1983. Andresen, *et al.* (1989) found that ET/PET was the most important factor in ECG. In an optimization program, they found that the summation of a daily optimized ECG $((ET/PET)^2(SR*FLAI)^{0.25})$ over a 37-day period (16 days before to 20 days after silking) provided higher correlations with county average corn yields than other periods examined. The model was developed with data from

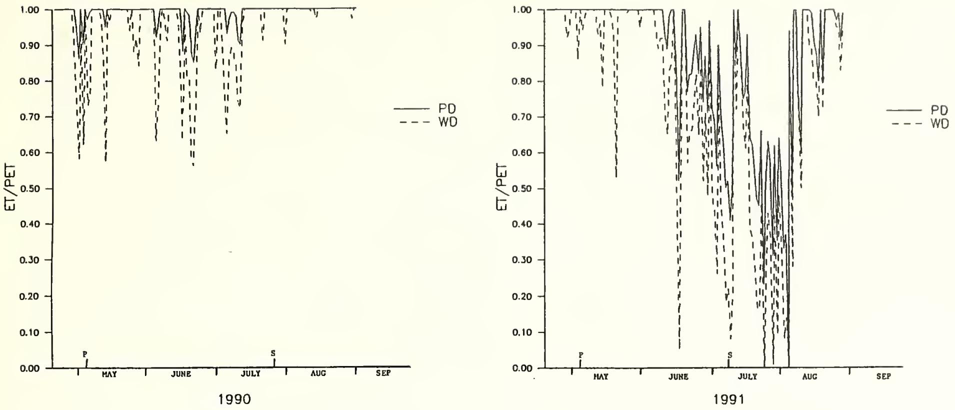

Figure 1. Daily series of ET/PET for poorly-drained and well-drained soils in Tippecanoe County for 1990 and 1991. The dates by which 50% of the District 4 corn acreage had been planted (P) and silked (S) are shown on the abscissa.

4 counties and independently tested with data from 14 other counties in Indiana (R = 0.83).

We have two objectives in this paper. The first is to show the relation of a technology trend and a soil moisture stress index summed over three periods, 120, 90, and 37 days, to the average corn yield in Tippecanoe County, Indiana. The second is to prepare the climatology of that moisture stress index based on the 1961-1991 period. Assuming that this climatological record is representative of the weather to come, the results of these two analyses will allow the probability of moisture stress and thereby the average corn yield for Tippecanoe County for 1992 and subsequent years to be estimated.

## MATERIALS AND METHODS

The SIMBAL (simulation of the soil water balance) program developed by Stuff and Dale (1978) for corn on a tile-drained Typic Argiaquoll (Chalmers silt loam) and later generalized (Dale, *et al.,* 1982) for both poorly-drained (PD) and well-drained (WD) soils was used to calculate the soil moisture under corn and the ratio of actual to potential evapotranspiration (ET/PET) for each day of the growing seasons, 1961 through 1991, for representative PD and WD soils in Tippecanoe County. For PD soils, the soil water balance is controlled by the corn rooting depth (estimated from date of corn silking), the plant available water holding capacity in each soil layer, infiltrated precipitation, depth of the field drainage tiles, capillary flow upward from the shallow water table into the corn root zone, and the evapotranspiration loss. For WD soils, the simulation is the same except there is no modeled shallow water table and capillary flow into the corn root zone.

The daily precipitation and pan evaporation data were observed at the NWS-Purdue University climatological station, West Lafayette 6 NW, at the Agronomy Research Cen-

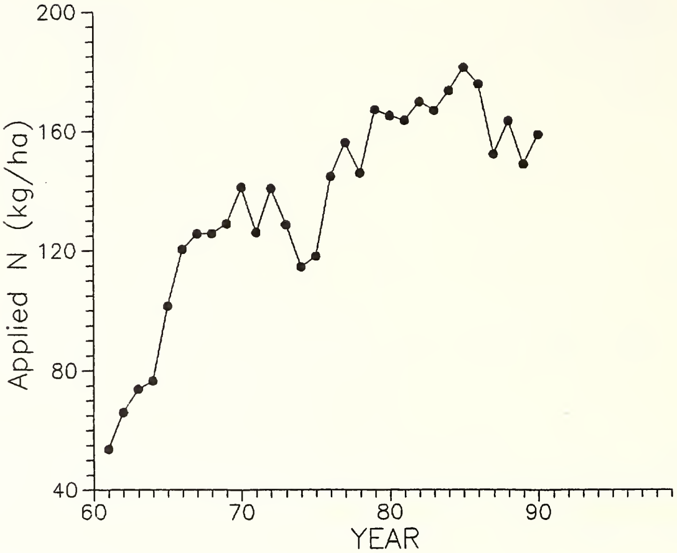

Figure 2. Indiana State average nitrogen applicawwwtion on corn land for indicated year, 1961-1990 (data from Indiana Agricultural Statistics Service).

ter (U.S. Dep. Commerce, 1961-1991). The soil characteristics for a representative PD soil in Tippecanoe County, a Typic Argiaquoll (Chalmers silt loam), were those used by Dale, *et al.* (1982, Table 1). This PD soil has a plant-available water holding capacity of 235 mm in the top 105 cm and an additional average capillary supply of about 87 mm from the shallow water table during the 100-day seasons centered at the date of corn silking (Stuff and Dale, 1978, Table 1). The soil characteristics for a representative WD soil, a Typic Argiudoll (Elston), were those used by Paisarnuchapong (1981, Table 3). This WD soil has a plant-available water holding capacity of 189 mm in the top 150 cm. The average date by which 50% of the corn acreage in Tippecanoe County had silked for each year was assumed to be the same as that for Crop Reporting District 4, published by the Indiana Agricultural Statistics Service (1961-1991).

In SIMBAL, the daily ET/PET ratio is calculated as a function of the product of the pan evaporation ($E_p$) and the soil moisture deficit (1-PAV), where PAV is the ratio of the plant-available soil water to the available water holding capacity in the corn root zone. If there is little $E_p$ and little (1-PAV), the ET/PET ratio is 1, and there is no moisture stress. If $E_p$ and/or (1-PAV) are great, ET/PET is less than 1, and the corn is stressed. While the ET/PET ratio is referred to as a measure of soil-plant "moisture stress", please note it is really a "non-moisture stress" variable, i.e., the higher the ET/PET the less the stress.

Plots of the calculated daily ET/PET ratios are shown in Figure 1 for both a PD (Chalmers, Typic Argiaquoll) and a WD (Elston, Typic Argiudoll) soil for 1990 and 1991. The differences shown in the seasonal ET/PET patterns raised two procedural questions which had to be answered.

First, moisture stress occurs more often (ET/PET less than 1) on WD than on PD soils. Since the average county corn yield is based on all corn acreages in the county, regardless of soil types, how should a representative daily moisture stress variable for Tippecanoe County be calculated? Since about 43% of the corn in Tippecanoe County is grown on WD soils and about 57% on PD soils (Andresen, 1987, p. 127), the ET/PET ratios for the WD (Elston) and PD (Chalmers) SIMBAL estimates were weighted accordingly to estimate the daily ET/PET for Tippecanoe County.

Second, moisture stress can occur at any time during the season. In 1990, there was little stress. It occurred only for about a week after planting, and the corn yields in Tippecanoe County averaged 9.06 t $ha^{-1}$ (145 bu $a^{-1}$). In 1991, there was considerable moisture stress, beginning even on the PD soil about 4 weeks before corn silking and continuing through grain maturity. Tippecanoe County corn yield was 4.75 t $ha^{-1}$ (76 bu $a^{-1}$). Over what critical period should the daily ET/PET values be summed to obtain the most appropriate stress index for predicting final corn yield? The use of moisture stress indices for three different phenological periods (120, 90, and 37 days) was examined in this paper.

The interaction between weather and agricultural technology has always posed difficult problems, both in evaluating the effect of technology and in determining weather effects on crop yields. In wrestling with these problems before the eighties, Nelson and Dale (1978) found that the amount of fertilizer nitrogen (N) applied to corn land was a better covariable than trend (T). They used N as a marker for all technology, assuming that a farmer who used sufficient levels of N on corn land would also use sufficient levels of other fertilizers, appropriate corn hybrids, pesticides, and other crop management technologies. Since the mid 1980's, however, with increased environmental concern about nitrate leaching into the ground water, increased nitrogen prices, more efficient methods of N application, and the use of new corn hybrid varieties requiring less N, nitrogen application is no longer increasing in Indiana (Figure 2). Yet, corn yields maintained an upward trend through the eighties. Therefore, year (T), rather than N, was used as a linear technology covariate in the multiple regression model,

$$Y = ß_0 + ß_1T + ß_2S_c + \epsilon, \qquad [1]$$

where Y is the average Tippecanoe County corn yield (Indiana Agric. Stat. Srvc, 1961-1990) in t $ha^{-1}$, T is year from 61 to 90, and $S_c$ is the moisture stress index or the sum of the daily ET/PET values for the respective critical (c) phenological period, 120, 90, or 37 days. Because weather usually affects crop yields as an interaction with technology, not merely as a linear factor (Mach and Dale, 1985; Featherstone, *et al.,* 1991), a second regression model was investigated which included an interaction term ($T * S_c$),

$$Y = ß_0 + ß_1T + ß_2S_c + ß_3(T * S_c) + \epsilon. \qquad [2]$$

Since final USDA corn yield estimates for Tippecanoe County were not yet available for 1991, these data could not be used in the regression analysis. Also, the data for 1970 were not used, the year a disastrous Southern Corn Leaf Blight was experienced in the eastern Corn Belt (Crane and Stierwalt, 1971). This left 29 years in the fitted regressions. Weighted $S_c$ indices were also computed for 1970 and 1991, the years not used in the weather-technology-yield regressions, to create frequencies and cumulative fre-

Table 1. Summary regression statistics for models [1] and [2] for three different critical periods of moisture stress ($S_c$), n = 29, 1961-1990 excluding 1970.

Model [1] $Y = \beta_0 + \beta_1 T + \beta_2 S + \epsilon$

| $S_c$ | F value* | Root MSE t ha | Adj $R^2$ | C.V. % |
|---|---|---|---|---|
| $S_{120}$ | 25.6 | 0.86 | 0.64 | 13.0 |
| $S_{90}$ | 27.0 | 0.85 | 0.65 | 12.8 |
| $S_{37}$ | 30.3 | 0.81 | 0.68 | 12.3 |

Model [2] $Y = \beta_0 + \beta_1 T + \beta_2 S_c + \beta_3 (T * S_c) + \epsilon$

| $S_c$ | F value* | Root MSE t ha | Adj $R^2$ | C.V. % |
|---|---|---|---|---|
| $S_{120}$ | 14.3 | 0.92 | 0.59 | 13.8 |
| $S_{90}$ | 21.0 | 0.81 | 0.68 | 12.2 |
| $S_{37}$ | 17.5 | 0.86 | 0.64 | 13.0 |

*All F values significant at $\alpha = 0.0001$.

quencies of the $S_c$ indices for the 1961-1991 period. The empirical cumulative frequencies were estimated as m/(n + 1), where m is the rank of the respective $S_c$ index from the lowest to the highest values and n is the number of years, 31 in this case. These empirical probability curves were also fitted with a beta distribution. Yao (1969) showed that the beta distribution,

$$F(X) = \frac{\Gamma(p)\,\Gamma(q)}{\Gamma(p+q)} \int_0^X X^{p-1} (1 - X)^{q-1} dX, \; 0 \leq X \leq 1,$$

provided excellent fits of the daily ratios of ET/PET. The parameter estimates of p and q were calculated from the average daily $S_c$ indices by the method of moments and used to obtain the percentage probability points of the beta distribution tabled in the CRC Handbook (Beyer, 1968, pp. 251-265).

## RESULTS AND DISCUSSION

**Corn Yield, Technology, and Moisture Stress Relations.** The summary regres-

Table 2. Regression coefficients (with their standard errors) for indicated model and critical period of moisture stress ($S_c$).

| | | Regression Coefficients for Model [1] | |
|---|---|---|---|
| $S_c$ | Y-intercept | T(Year) | $S_c$ |
| $S_{120}$ | -10.90$^{**}$(±2.78) | 0.12$^{**}$ (±0.02) | 0.076$^{**}$ (±0.018) |
| $S_{90}$ | -10.39$^{**}$(±2.34) | 0.11$^{**}$ (±0.02) | 0.10$^{**}$ (±0.02) |
| $S_{37}$ | -10.17$^{**}$(±2.34) | 0.13$^{**}$ (±0.02) | 0.22$^{**}$ (±0.04) |

| | | Regression Coefficients for Model [2] | | |
|---|---|---|---|---|
| $S_c$ | Y-intercept | T(Year) | $S_c$ | T*Sc |
| $S_{120}$ | -3.02 (±16.4) | 0.025 (±0.20) | 0.0028 (±0.15) | 0.00091 (±0.0019) |
| $S_{90}$ | 12.78 (±13.2) | -0.19 (±0.17) | -0.19 (±0.16) | 0.0038$^{*}$ (±0.0021) |
| $S_{37}$ | -3.75 (±14.2) | 0.046 (±0.18) | 0.026 (±0.42) | 0.0024 (±0.0053) |

$^{*}$ Significant at $\alpha = 0.15$.

$^{**}$ Significant at $\alpha = 0.0001$.

sion statistics for models [1] and [2], each for three different summation periods of $S_c$ ($S_{120}$, $S_{90}$, and $S_{37}$) are shown in Table 1. The F-values for all six regressions shown in Table 1 were significant at the $\alpha = 0.0001$ level.

The models were associated with about 2/3 of the variance in the average county corn yield series (adjusted $R^2$ values ranged from 0.59 to 0.68). The summary statistics provide little help in selecting between models [1] and [2] and the two shorter stress periods. The adjusted $R^2$ values (0.68), root mean square errors (0.81 t ha$^{-1}$ (13.0 bu a$^{-1}$)), and the coefficients of variation (12.2, 12.3 percent) were almost identical for [1] with $S_{37}$ and [2] with $S_{90}$.

The estimated regression coefficients with their standard errors are shown in Table 2 for the six regressions. All of the coefficients for [1] were significant at $\alpha = 0.0001$. There was no significant correlation between $S_c$ and T and, thus, no problem with multicollinearity. When the interaction term was included, only the coefficient for the interaction term in [2] for $S_{90}$ was significant at $\alpha = 0.15$. Multicollinearity (high correlation between the linear terms and their products) causes overestimates of the standard errors of the coefficients (Green, 1978, p. 226) but does not bias the estimates. Perhaps, more definitive results should not be expected when using a county average corn yield for the Y variable, a simple trend variable (T) to represent all technology, and precipitation from a single weather station to estimate the weighted $S_c$ for the county.

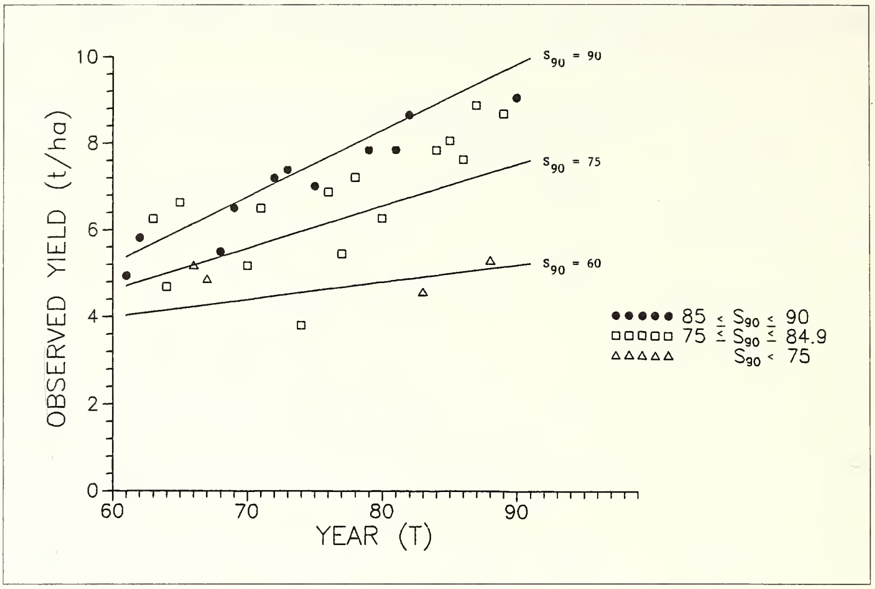

Figure 3. Average Tippecanoe County corn yield plotted on year with indicated category of moisture stress ($S_{90}$) experienced during the 90-day period from 39 days before to 50 days after silking in that year. Solid lines are [3] evaluated of $S_{90}$ levels of 90 (none), 75 (moderate), and 60 (severe moisture stress).

Model [2] for $S_{90}$ is reproduced from Table 2 as [3],

$$Y = 12.78 - 0.19\,T - 0.19\,S_{90} + 0.0038\,(T * S_{90}), \qquad [3]$$

and also in Figure 3, arbitrarily evaluated for $S_{90}$ values of 90, 75, and 60 on the scattergram of average Tippecanoe County corn yields on year. The $S_{90}$ value of 90 is a bound of no moisture stress, 60 is just below the lowest value (highest stress) observed in the 31-yr period (61.8 in 1988), and 75 is halfway between. The 75 and 60 values can be considered moderate and severe moisture stress, respectively.

The interaction model [3] in Figure 3 shows increasing variability in average corn yields. While agricultural technology continues to increase the yield potential with favorable weather, yields are still severely reduced with insufficient precipitation. For example, note that the yields in 1983 and 1988 were below those in the 60's. Technology has increased yields an estimated 0.15 t $ha^{-1}$ $yr^{-1}$ (2.4 bu $a^{-1}$ $yr^{-1}$) if there were no moisture stress ($S_{90}$ = 90), but only 0.04 t $ha^{-1}$ $yr^{-1}$ (0.6 bu $a^{-1}$ $yr^{-1}$) with severe moisture stress ($S_{90}$ = 60). With 1990 technology (T = 90), each deficit unit of $S_{90}$ (ET/PET) reduces the average county corn yield 0.15 t $ha^{-1}$ (2.4 bu $a^{-1}$).

For the 37-day stress period, the interaction term was not significant, and model [1] with $S_{37}$ is reproduced from Table 2 as [4],

$$Y = -10.17 + 0.13\,T + 0.22\,S_{37}, \qquad [4]$$

and also in Figure 4, evaluated for arbitrary $S_{37}$ values of 37, 30, and 23 on the scattergram of average county corn yields on year. Again, 37 is the bound of no mois-

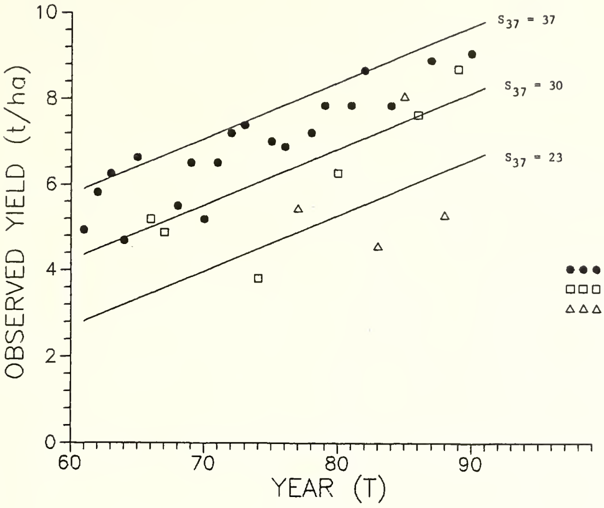

Figure 4. Average Tippecanoe County corn yield on year with each yield plotted with indicated category of moisture stress ($S_{37}$) experienced in that year during the 37-day period from 16 days before to 20 days after silking. Solid lines are [4] evaluated for $S_{37}$ levels of 37 (none), 30 (moderate), and 23 (severe moisture stress).

ture stress, 23 is just above the lowest value observed (22.4 in 1991), and 30 is half way between. The linear variable model [4] shows that technology increased yields an average of 0.13 t ha$^{-1}$ yr$^{-1}$ (2.1 bu a$^{-1}$ yr$^{-1}$) independent of moisture stress. Each deficit unit of $S_{37}$ (ET/PET) decreased the average corn yield 0.22 t ha$^{-1}$ (3.5 bu a$^{-1}$) independent of technology. Only further testing of [3] and [4] with independent data will determine their relative predictive abilities, but certainly weather remains a major source of the variability in corn yields.

In 1991, the $S_{90}$ index was 65.9. With [3] and T = 91, the predicted average corn yield for Tippecanoe County is 5.76 ± 0.81 t ha$^{-1}$ (92.2 ± 13.0 bu a$^{-1}$), down 41% from the potential 1991 yield of 9.50 t ha$^{-1}$ (152.0 bu a$^{-1}$) with $S_{90} = 90$. The $S_{37}$ index in 1991 was 22.4, the lowest in the 1961-1991 record. If this index were used in [4], again with T = 91, the predicted Tippecanoe County average corn yield in 1991 is estimated at 6.59 t ha$^{-1}$ (105.4 bu a$^{-1}$), down 33% from the potential 1991 yield of 9.80 t ha$^{-1}$ (156.8 bu a$^{-1}$) with $S_{37} = 37$.

The advantage of using $S_{37}$ and [4] is that a preliminary prediction of the 1991 crop yield could be made 20 days after corn silking (Table 3) or on 27 July 1991. If $S_{90}$ and [3] were used, the prediction could not be made until 50 days after silking or on 26 August 1991, when the corn grain filling period was essentially completed. With the corn growing season over, model [3] with $S_{90}$ should give the best prediction, recognizing that the prediction goes beyond the data range used for T in both models and for $S_{37}$ in [4]. The preliminary USDA 1991 estimated corn yield for Tippecanoe County was 4.75 t ha$^{-1}$ (76 bu a$^{-1}$), less than both [3] and [4] estimates.

**Climatology of Moisture Stress.** The unweighted stress indices ($S_c$) for the PD

Table 3. Moisture stress indices for both poorly-drained (Chalmers) and well-drained (Elston) soils, and the weighted average for 120-, 90-, and 37-day periods during the indicated growing season in Tippecanoe County, Indiana, 1961-1991. The county average corn yield and the average date of corn silking are also shown for each year.

| | | | Stress Indices | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Average Yield t ha$^{-1}$ | Silk Date | Chalmers PD | | | Elston WD | | | Weighted Average | | |
| | | | 120D | 90D | 37D | 120D | 90D | 37D | 120D | 90D | 37D |
| 61 | 4.94 | 8/07 | 119.1 | 89.0 | 36.2 | 108.5 | 80.8 | 32.4 | 114.5 | 85.4 | 36.8 |
| 62 | 5.81 | 7/21 | 119.1 | 89.4 | 37.0 | 112.4 | 83.8 | 36.5 | 116.2 | 86.9 | 36.7 |
| 63 | 6.25 | 7/30 | 117.1 | 87.1 | 35.6 | 107.1 | 77.6 | 32.0 | 112.8 | 83.4 | 36.5 |
| 64 | 4.69 | 7/19 | 111.4 | 82.0 | 34.9 | 96.9 | 70.7 | 30.5 | 105.7 | 77.3 | 33.3 |
| 65 | 6.63 | 7/24 | 115.8 | 85.8 | 36.1 | 106.8 | 77.9 | 32.3 | 112.0 | 82.4 | 34.2 |
| 66 | 5.19 | 7/28 | 103.3 | 73.8 | 29.4 | 84.4 | 57.8 | 22.7 | 91.5 | 64.0 | 28.0 |
| 67 | 4.88 | 8/01 | 103.8 | 73.9 | 30.1 | 84.9 | 57.4 | 23.0 | 94.6 | 67.5 | 28.9 |
| 68 | 5.50 | 7/29 | 119.6 | 89.6 | 36.6 | 116.1 | 86.2 | 34.3 | 118.1 | 88.6 | 36.2 |
| 69 | 6.50 | 7/27 | 119.5 | 89.5 | 36.5 | 112.8 | 83.2 | 33.5 | 116.3 | 86.5 | 35.3 |
| 70 | 5.19* | 7/27 | 117.8 | 87.8 | 36.0 | 108.3 | 78.6 | 32.4 | 113.7 | 83.8 | 34.6 |
| 71 | 6.50 | 7/24 | 118.6 | 89.1 | 36.9 | 106.5 | 79.5 | 35.5 | 113.4 | 84.8 | 36.2 |
| 72 | 7.19 | 7/26 | 118.4 | 89.2 | 36.8 | 109.5 | 83.4 | 34.1 | 114.6 | 86.7 | 35.9 |
| 73 | 7.38 | 7/28 | 119.2 | 89.2 | 36.3 | 111.9 | 82.4 | 32.7 | 116.0 | 86.2 | 35.1 |
| 74 | 3.81 | 8/09 | 111.6 | 81.6 | 30.6 | 99.0 | 70.1 | 23.1 | 108.1 | 78.3 | 31.0 |
| 75 | 7.00 | 7/16 | 119.1 | 89.2 | 36.7 | 111.2 | 82.5 | 32.8 | 115.7 | 86.3 | 35.3 |
| 76 | 6.87 | 7/21 | 114.1 | 84.4 | 35.7 | 98.9 | 71.1 | 30.9 | 107.2 | 78.4 | 33.6 |
| 77 | 5.46 | 7/13 | 109.7 | 81.4 | 29.9 | 94.5 | 70.8 | 21.7 | 103.2 | 76.5 | 26.4 |
| 78 | 7.21 | 7/26 | 119.4 | 89.4 | 36.9 | 107.7 | 78.9 | 33.9 | 113.5 | 84.5 | 35.3 |
| 79 | 7.84 | 7/25 | 119.0 | 89.3 | 37.0 | 111.9 | 84.6 | 36.9 | 115.6 | 87.0 | 37.0 |
| 80 | 6.27 | 7/18 | 114.9 | 85.1 | 33.2 | 104.1 | 75.2 | 26.3 | 110.3 | 80.9 | 30.3 |
| 81 | 7.84 | 7/31 | 119.5 | 89.9 | 36.9 | 112.4 | 83.3 | 35.6 | 116.7 | 88.6 | 36.9 |
| 82 | 8.65 | 7/15 | 117.4 | 89.2 | 36.6 | 105.9 | 79.5 | 33.1 | 112.2 | 86.9 | 35.1 |
| 83 | 4.58 | 7/26 | 96.6 | 74.7 | 26.8 | 79.6 | 57.2 | 20.5 | 92.1 | 62.6 | 23.1 |
| 84 | 7.84 | 7/24 | 109.2 | 83.8 | 36.5 | 82.6 | 66.3 | 30.4 | 102.1 | 77.6 | 33.2 |
| 85 | 8.06 | 7/15 | 104.0 | 79.0 | 27.9 | 88.4 | 70.5 | 23.1 | 97.3 | 75.3 | 25.8 |
| 86 | 7.62 | 7/16 | 113.1 | 83.1 | 34.9 | 101.7 | 72.1 | 29.7 | 108.2 | 78.4 | 32.7 |
| 87 | 8.88 | 7/07 | 109.4 | 85.1 | 35.1 | 94.8 | 77.2 | 31.7 | 103.1 | 81.7 | 33.6 |
| 88 | 5.31 | 7/19 | 79.7 | 64.6 | 28.3 | 64.0 | 58.2 | 27.2 | 72.9 | 61.8 | 27.8 |
| 89 | 8.69 | 7/24 | 111.1 | 81.6 | 32.5 | 93.7 | 68.1 | 25.9 | 103.6 | 75.8 | 29.7 |
| 90 | 9.06 | 7/24 | 119.1 | 89.3 | 36.8 | 114.0 | 85.8 | 36.0 | 116.9 | 87.8 | 36.5 |
| 91 | 4.75** | 7/07 | 101.1 | 71.1 | 25.6 | 87.8 | 58.9 | 18.2 | 95.4 | 65.9 | 22.4 |

* Southern Corn Leaf Blight epidemic; not used in regression (Crane and Stierwalt, 1971).

** Preliminary USDA estimate; not used in regression.

and WD soils for the three critical periods for Tippecanoe County are shown in Table 3 for each year from 1961 through 1991, together with the weighted average stress indices for the county, the date by which 50% of the corn had silked in the county, and the respective average county corn yields. The weighted $S_{37}$ value of 22.4 in 1991 was the

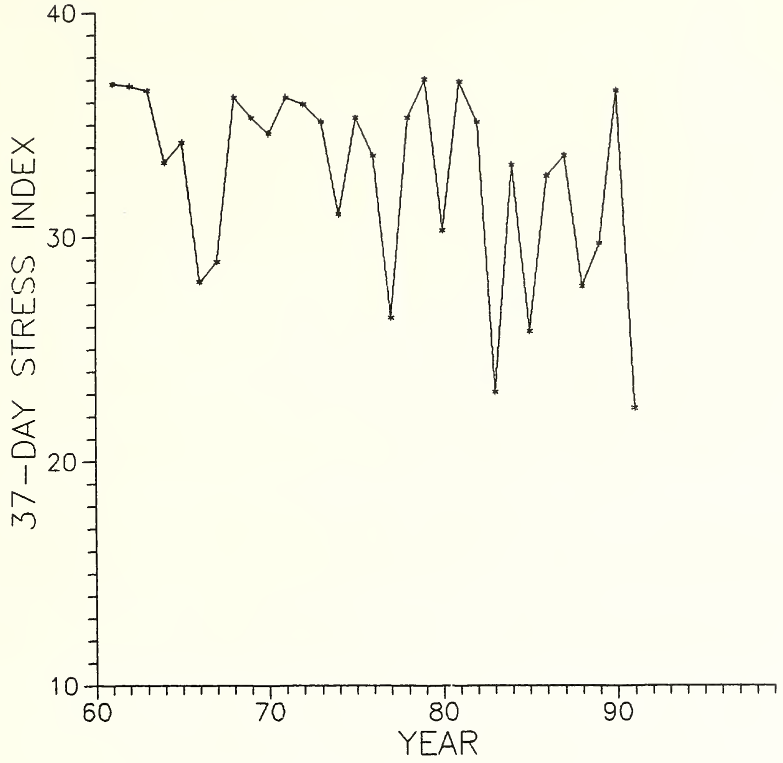

Figure 5. Weighted 37-day moisture stress index for Tippecanoe County on year, 1961-1991.

lowest (greatest stress) in the 1961-1991 period, but the lowest value (greatest stress) for both $S_{120}$ (72.9) and $S_{90}$ (61.8) occurred in 1988.

The weighted $S_{37}$ indices ($0.57\ S_{37\,PD} + 0.43\ S_{37\,WD}$) for Tippecanoe County are plotted for each year in Figure 5. While there may appear to be more stress in the eighties, the 1961-1991 series is too short for any conclusions about a changing climate. The correlation coefficient of $S_{37}$ on T is -0.32, not significant at the a= 0.05 level. For probability prediction purposes, the climatology of this 31-year period is assumed to be representative of the weather to come.

The frequency distribution (Figure 6) for the weighted $S_{37}$ indices for the 1961-1991 period shows high negative skewness. Only one year had an $S_{37}$ value less than 23, and 14 of the 31 years had $S_{37}$ values greater than 35. Since $S_{37}$ is included in $S_{90}$ and $S_{120}$, the three stress indices are highly correlated, e.g., the correlation between $S_{37}$ and $S_{90}$ is 0.88. Therefore, the frequencies for the $S_{90}$ and $S_{120}$ indices show the same highly skewed pattern as Figure 6, there being a greater probability for low moisture stress or "favorable weather" than for high moisture stress in Tippecanoe County, Indiana. Frequencies prepared from the unweighted $S_c$ indices in Table 3 show the skewness for the stress

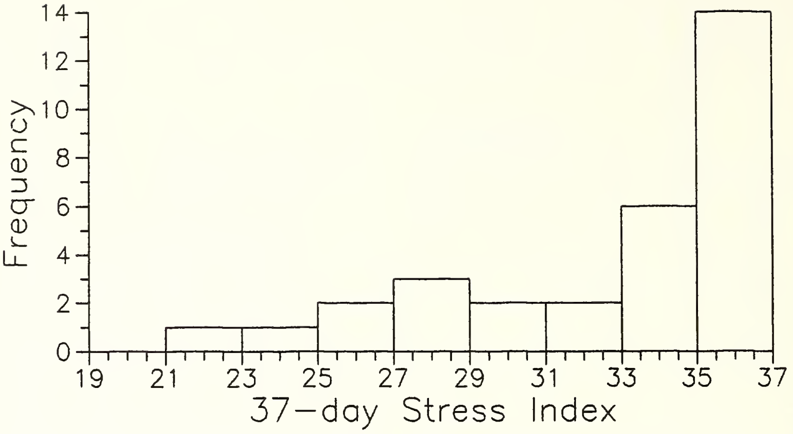

Figure 6. Frequency distribution of weighted 37-day moisture stress index for Tippecanoe County, 1961-1991.

indices on just PD soils greater, and for just WD soils lesser, than for the weighted stress indices.

The cumulative frequencies for $S_{90}$ and $S_{37}$ shown in Figure 7A and B, respectively, provide an estimate of the probability of having at least the indicated level of moisture stress in Tippecanoe County, again assuming that the last 31 years are a representative sample of the weather to come in the next few years. Both the empirical and fitted beta distribution curves are shown. (The moment estimates of the parameters in the beta distribution for $S_{90}$ were $\hat{p} = 10.95$ and $\hat{q} = 1.38$, and for $S_{37}$, $\hat{p} = 6.99$ and $\hat{q} = 0.88$.) From Figure 7B, the beta distribution probability of having an $S_{37}$ value less than 34 next year, or any year, is 50%. Using [4], T = 92 (forecasting beyond the sample data range of T) and $S_{37} = 34$, the estimated corn yield in 1992 is 9.3 t $ha^{-1}$ (149 bu $a^{-1}$). Thus, the probability of having an average Tippecanoe County corn yield less than 9.3 t $ha^{-1}$ is about 50% or, conversely, the probability of having a yield of 9.3 t $ha^{-1}$ or greater is 50%.

Similarly, the climatology of moisture stress shown in Figure 7A for $S_{90}$, preferred because $S_{90}$ includes critical growth and development stages before $S_{37}$ as well as the whole corn grain filling period, can be used with [3] and T = 92 to convert and double label the 90-day stress index abscissa to corresponding average county corn yields. Although the 90 $S_{90}$ bound imposes a predicted yield bound in 1992 of 9.7 t $ha^{-1}$ (155 bu $a^{-1}$) and the averaging process of the regression method decreases the predicted yield variability, the Figure 7A agroclimatology certainly provides a better estimate of the skewed corn yield distribution than a straight frequency of the heterogeneous 1961- 1991 yield series. Thus, the Figure 7A curve indicates that the probability of having an average county corn yield less than 5 t $ha^{-1}$ (80 bu $a^{-1}$) is about 2%, and the probability of having a yield less than 8 t $ha^{-1}$ (128 bu $a^{-1}$) is about 42%.

The agroclimatology of moisture stress and predicted corn yield is conditioned upon the accuracy of [3] and [4], SIMBAL, the representativeness of the measured precipitation used to model ET/PET for the county, the ability of the $S_c$ and T variables to repre-

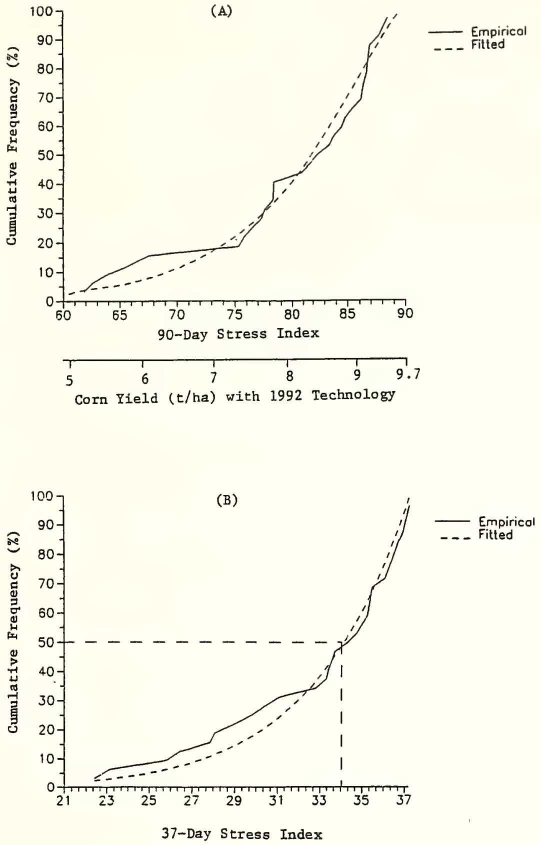

Figure 7. **A.** Empirical and fitted beta distribution probability of having at least indicated level of weighted moisture stress index for the 90-day period in Tippecanoe County, Indiana, based on 1961-1991 record. The second abscissa, labeled in t $ha^{-1}$, provides the probability of having at least the indicated average corn yield in 1992, estimated with [3] and T = 92. **B.** Empirical and fitted beta distribution probability of having at least the indicated level of weighted moisture stress index for the 37-day period in Tippecanoe County, Indiana, based on the 1961-1991 record. The rectangular dashed lines show that the beta distribution probability of having a moisture stress index less than 34 is 50%.

sent the major environmental and technological effects on corn yields, and finally the accuracy of the county average corn yield estimates by the Indiana Agricultural Statistics Service.

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## LITERATURE CITED

Acock, B. and M.C. Acock. 1991. Potential for using long-term field research data to develop and validate crop simulators. Agron. J. 83: 56-61.

Andresen, J.A. 1987. Corn yield prediction with a daily energy-crop growth variable for counties in Indiana. Ph.D.Thesis, Purdue Univ., West Lafayette, Indiana, 152 pp.

__________, R.F. Dale, J.J. Fletcher, and P.V. Preckel. 1989. Prediction of county-level corn yields using an energy-crop growth index. J. Climate 2: 48-56.

Beyer, W.H. 1968. CRC handbook of tables for probability and statistics. Chemical Rubber Co., Cleveland, Ohio, 642 pp.

Changnon, S.A. and J.C. Neill. 1968. A mesoscale study of corn-weather relations in Illinois. Trans. Illinois State Acad. Sci. 60: 221-230.

Crane, P.L. and T.R. Stierwalt. 1971. Performance of commercial dent corn hybrids in Indiana, 1967-1970. Res. Bull. 874. Agr. Exp. Sta., Purdue Univ., West Lafayette, Indiana, 7 pp.

Dale, R.F. 1948. The influence of phenological period rainfall on the yield of corn in Iowa. M.S. Thesis, Iowa State Univ., Ames, Iowa, 71 pp.

__________ and H.F. Hodges. 1975. Weather and corn yield study. Final Report to Environmental Data Service, NOAA on NOAA USDC Grant NG-44-72, Agron. Dep., Purdue Univ., West Lafayette, Indiana, 97 pp.

__________, W.L. Nelson, K.L. Scheeringa, R.G. Stuff, and H.F. Reetz. 1982. Generalization and testing of a soil moisture budget for different drainage conditions. J. Appl. Meteorol. 21: 1417-1426.

Featherstone A.M., J.J. Fletcher, R.F. Dale, and H.R. Sinclair. 1991. Comparison of net returns under alternative tillage systems considering spatial weather variability. J. Prod. Agr. 4: 166-173.

Green, Paul E. 1978. Analyzing multivariate data. Dryden Press, Hinsdale, Illinois, 519 pp.

Hanway, J.J. and W.A. Russell. 1969. Dry-matter accumulation in corn (*Zea mays* L.) plants: Comparisons among single-cross hybrids. Agron. J. 61: 947-951.

Indiana Agricultural Statistics Service. 1961-1991. Indiana Agricultural Statistics 1961, 1962,...,1991. USDA-Purdue Univ., Agr. Exp. Sta., West Lafayette, Indiana.

Mach, M.A. and R.F. Dale. 1983. A methodology for considering the effect of weather on the response of corn yields to added fertilizer: A case study in Indiana with nitrogen. Proc. Indiana Acad. Sci. 92: 453-462.

Nelson, W.L. and R.F. Dale. 1978. Effect of trend or technology variables and record period on prediction of corn yields with weather variables. J. Appl. Meteorol. 17: 926-933.

Paisarnuchapong, O. 1981. Weather and irrigation scheduling. M.S. Thesis, Purdue Univ., West Lafayette, Indiana, 120 pp.

Sass, J.B. and F.A. Loeffel. 1959. Development of axillary buds in maize in relation to barrenness. Agron. J. 51: 484-486.

Shaw, R.H. 1977. Water use and requirements of maize. A review. *In:* W. Baier and R.H. Shaw (Eds.), *Agrometeorology of the Maize Crop,* pp. 119-134, World Meteorological Organization, Geneva, Pub. 481, 454 pp.

Stuff, R.G., H.F. Hodges, R.F. Dale, W.E. Nyquist, W.L. Nelson, and K.L. Scheeringa. 1979. Measurement of short-period corn growth. Res. Bull. 961, Agr. Exp. Sta., Purdue Univ., West Lafayette, 20 pp.

__________ and R.F. Dale. 1978. A soil moisture budget model accounting for shallow water table influences. Soil Sci. Soc. Amer. J. 42: 637-643.

Thompson, L.M. 1969. Weather and technology in the production of corn in the U.S. Corn Belt. Agron. J. 61: 453-456.

U.S. Dep. Commerce. 1961, 1962,...,1991. Climatological Data, Indiana, Vols. 66-96. Nat. Climatic Center, Asheville, North Carolina.

Yao, A.Y.M. 1969. The R index for plant water requirement. Agr. Meteorol. 6: 250-273.

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# FISHES OF THE TIPPECANOE RIVER, INDIANA: AN OUTSTANDING MIDWESTERN STREAM

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ABSTRACT: A total of 26 fish samples, taken at 22 sites along the length of the Tippecanoe River from 1985 through 1987, yielded 68 species. Historic and recent ichthyological records increase the total number of fish species known from the river to 84. The fish fauna of the Tippecanoe River is diverse and includes a number of species that are rare or declining throughout their historic ranges. Thus, the Tippecanoe River is a valuable aquatic resource that should be protected from further modification. A synopsis of distributional and habitat information on uncommon fishes that are extant in the river is presented in this paper. The uncommon species are *Ichthyomyzon bdellium, Hybopsis amblops, Notropis buchanani, Etheostoma camurum, E. maculatum, E. pellucidum, E. tippecanoe, Percina copelandi, P. evides,* and *P. shumardi.* Additionally, a rare form of logperch, *Percina caprodes manitou,* was identified from the Tippecanoe River. This subspecies is found in the glacial lakes region of northern Indiana and possibly further north. Type specimens of two nominal forms of *Percina* previously described from the glacial lakes of northern Indiana were examined. A preliminary analysis of the taxonomic status of *P. c. manitou* is presented.

## INTRODUCTION

The earliest studies of Tippecanoe River fishes were published in the late 1800s and early 1900s by David Starr Jordan and his proteges, Barton W. Evermann, Oliver P. Jenkins, and Carl H. Eigenmann. Jordan (1877) listed collections from three lakes tributary to the Tippecanoe River and described *P. manitou,* now considered a subspecies of *P. caprodes,* from Lake Manitou. Evermann and Jenkins (1889) reported fish collections made by Jenkins, who boated from Lake Maxinkuckee to the confluence of the Tippecanoe and Wabash rivers in August 1886; and by Evermann during his survey of the waters of Carroll County in August 1887. Jordan (1889) presented a list of fishes collected by Evermann in September 1888 from the Tippecanoe River at Marshland (now Delong) in Fulton County and described the Tippecanoe River as "one of the best streams in the State for the collection of darters". Evermann's collection included the type specimens of *Etheostoma tippecanoe,* formally described by Jordan and Evermann (1891). P. Kirsch also made a collection at the "Marshland" locality in August 1889 (Zorach and Raney, 1967). Eigenmann and Beeson (1894) and Hay (1894, 1902) published Statewide lists of Indiana fishes that included specific Tippecanoe River localities; however, these records were drawn largely from the publications of Evermann, Jenkins, and Jordan.

Ichthyological work in the Tippecanoe River drainage was apparently suspended for about 25 years, until publication of Evermann and Clark's (1920) exhaustive study of Lake Maxinkuckee. During the mid-1920s, several ichthyological collections were made in the Tippecanoe River by H.R. Becker and Carl L. Hubbs.

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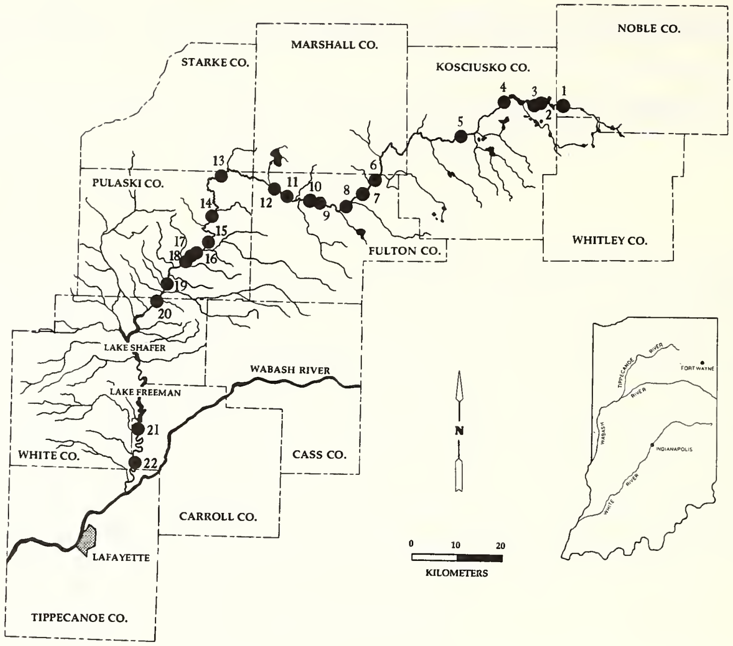

Figure 1. Collection sites (solid circles) on the Tippecanoe River, 12 July 1985 to 20 September 1987. Site numbers are identified in Table 1. Map from Cummings and Berlocher (1990).

Another 15 years of inactivity was followed by Shelby D. Gerking's Statewide survey, initiated in 1940, and publication of a comprehensive study on Indiana fish distributions (Gerking, 1945). Eight original collections from the Tippecanoe River were reported by Gerking (1945). The most recent publication to address Tippecanoe River fishes was the *Annotated Key to the Fishes of Indiana* (Nelson and Gerking, 1968), an update of the nomenclature and distribution of the Indiana ichthyofauna as reported by Gerking (1945).

The present study was initiated to determine the status and distribution of rare darters in Indiana. The scope was expanded to a general survey of the Tippecanoe River, because of the high diversity of fishes encountered and the discovery of several species that are now rare in the Midwest. Collection of *Percina caprodes manitou* prompted a preliminary analysis of its taxonomic status.

## STUDY AREA

The Tippecanoe River drains approximately 4895 square kilometers of northern and west-central Indiana (Wright, 1932). Headwaters of the Tippecanoe drainage are in Whitley and Noble Counties, and the river flows west-southwest for about 110 kilometers (Cummings and Berlocher, 1990) before emptying into the Wabash River in northeastern Tippecanoe County.

The upper drainage — above sample site 13 (Figure 1) in extreme northeast Pulaski Co. — is found in the Northern Lakes Natural Region, which is characterized by numerous glacial lakes (Homoya, *et al.,* 1985). This area is covered with complex Wisconsinan glacial deposits which are, in places, over 137 meters thick (Homoya, *et al.,* 1985). Natural community types in the Northern Lakes Natural Region include bog, fen, marsh, prairie, sedge meadow, swamp, seep spring, lake, and various deciduous forest types. Streams typically are clear, with medium to low gradients, and sand and gravel beds (Homoya, *et al.,* 1985).

The middle Tippecanoe drainage is in the Kankakee Sand Section of the Grand Prairie Natural Region (sample sites 13-20) (Figure 1) until the Lake Freeman impoundment of the lower river where it enters the Tipton Till Plain Section of the Central Till Plain Natural Region (sample sites 21-22) (Homoya, *et al.,* 1985). The Kankakee Sand Section is characterized by prairie and savanna communities associated with sandy soils. The Tipton Till Plain Section is a mostly undissected plain formerly covered by an extensive beech-maple-oak forest (Homoya, *et al.,* 1985).

Two large impoundments (Lake Shafer and Lake Freeman) have been constructed on the lower Tippecanoe River. Residential and recreational development is present along the banks of the river and is especially widespread in the glacial lakes region. Still, the banks are primarily wooded. Undeveloped lands bordering the river include the Tippecanoe River State Park and Winamac State Fish and Wildlife Area, both located in the middle Tippecanoe drainage. Most of the tributary streams have been channelized for agricultural drainage.

Tippecanoe River substrates are primarily clean gravel and sand. Cobble and, to a lesser extent, large boulders are present in some reaches. Moderate silt accumulation near stream margins and organic enrichment, as evidenced by abundant filamentous algae, was apparent at most sample sites.

## MATERIALS AND METHODS

A total of 26 samples of fishes was taken at 22 sites along the length of the Tippecanoe River between 12 July 1985 and 20 September 1987 (Table 1, Figure 1). Collections were made with a 3 m x 1.2 m minnow seine and a 9 m x 1.2 m bag seine, each with 3.2 mm mesh. Representatives of each species were preserved in 10% formalin and stored in 70% ethanol. All specimens were deposited at the Illinois Natural History Survey (INHS). Additional museum specimens from the University of Michigan Museum of Zoology (UMMZ) and U.S. National Museum (USNM) were examined. Nomenclature follows Page and Burr (1991).

## RESULTS AND DISCUSSION

A total of 68 fish species was collected (Table 2). Seven species not previously reported from the drainage were found: *Notropis buchanani, Extrarius aestivalis, Phenacobius mirabilis, Ictiobus bubalus, Carpiodes cyprinus, Percina copelandi,* and *P. shumardi.*

Sixteen species recorded from the Tippecanoe drainage prior to 1980 (Evermann and Jenkins, 1889; Blatchley, 1938; Gerking, 1945; Rohde, 1980) were not captured during this survey (Table 3). One species, the harelip sucker (*Moxostoma lacerum*),

Table 1. Collection sites, dates, and habitat characteristics for the Tippecanoe River, Indiana.

1. Wilmot, Highway 5, Noble County; Sec. 19, T33N, R8E; 13 July 1985; rubble riffles and pools.

2. North Webster, Kosciusko County; Sec. 15, T33N, R7E; 13 July 1985; gravel and sand pools and riffles.

3. 0.5 miles southwest of North Webster, Kosciusko County; Sec. 15, T33N, R7E; 13 July and 7 September 1985; gravel-rubble, sand, and mud pools and runs; emergent vegetation.

4. Oswego, Kosciusko County; Sec. 14, T33N, R6E; 13 July 1985; sand and debris.

5. 4 miles west of Warsaw, Kosciusko County; Sec. 11, T32N, R5E; 12 July 1985; vegetated rubble riffle.

6. Talma, Fulton County; Sec. 12, T31N, R3E; 12 July 1985 and 16 July 1987; gravel, rubble riffle; sandy run and pools.

7. 5 miles northeast of Rochester, Fulton County; Sec. 22, T31N, R3E; 14 July 1985; rocky riffle; gravel, sand, and silt.

8. Route 31 bridge, 3 miles north of Rochester, Fulton County; Sec. 29, T31N, R3E; 26 July 1987; sand, gravel, brush.

9. County road crossing, 1.5 miles north of Pershing, Fulton County; Sec. 21, T31N, R2E; 20 September 1987; rubble riffles.

10. 2 miles north of Pershing, Fulton County; Sec. 21, T31N, R2E; 29 July 1987; gravel and sand.

11. Leiters Ford, Fulton County; Sec. 23, T31N, R1E; 14 July 1985; rubble riffle, sandy pools and runs.

12. Delong, Fulton County; Sec. 9, T31N, R1E; 14 July and 7 September 1985, 20 September 1987; large rock riffle and gravel runs.

13. Mouth of slough, 1 mile south of Ora, Pulaski County; Sec. 5, T31N, R1W; 19 September 1987; mud and brush.

14. 4 miles northeast of Winamac, Pulaski County; Sec. 32, T31N, R1W; 14 July 1985; large rocky riffle.

15. 3 miles south of Winamac, Pulaski County; Sec. 35-36,T30N, R2W; 15 July 1985; rocky riffle and pools.

16. Route 119, 3 miles south of Winamac, Pulaski County; Sec. 35-36, T30N, R2W; 7 September 1987; rubble riffle, sandy pools and runs.

17. 6 miles south of Winamac, Pulaski County; Sec. 35-36, T30N, R2W; 27 July 1985; collected by Thomas P. Simon.

18. 2 miles northeast of Pulaski, Pulaski County; Sec. 3, T29N, R2W; 25 July 1987.

19. 4 miles east of Lakeside, Pulaski County; Sec. 30, T29N, R2W; 15 July 1985; large rubble riffle, sandy pools.

20. Mouth of Ackerman Ditch, 3 miles west of Headlee, White County; Sec. 1, T28N, R3W; 19 September 1987; silt and sand backwater, cobble and boulder run.

21. Below Oakdale Dam (Lake Freeman), Carroll County; Sec. 33, T26N, R3W; 20 September 1987; gravel runs, some cobbles and boulders.

22. 3 miles north of Americus, Carroll County; Sec. 33, T25N, R3W; 15 July 1985; large gravel and rubble riffles and runs.

historically known from the Tippecanoe River (Evermann and Jenkins, 1889), is now extinct (Jenkins, 1980). The total number of species known from the river is 84.

Taxa taken only in the upper extremes of the Tippecanoe River (upper five sample sites) during this study were *Erimyzon sucetta, Noturus gyrinus, Etheostoma exile, E. flabellare, E. microperca, Perca flavescens,* and *Percina c. manitou.* These species are primarily associated with the glacial lakes of the upper watershed. Species captured only in the lower river (below Lake Schafer) were *Extrarius aestivalis, P. copelandi,* and *P. shumardi.*

Species generally distributed in the Tippecanoe River, based on the number of capture sites, were: *Cyprinella spiloptera* (19 sites), *Pimephales notatus* (18), *Nocomis micropogon* (17), *Lepomis megalotis* (17), *Etheostoma nigrum* (17), *E. blennioides* (16), *Notropis ludibundus* (14), *Cottus bairdi* (14), *Luxilus chrysocephalus* (13), *Hypentelium nigricans* (13), *Ambloplites rupestris* (13), and *Percina sciera* (12). Species that appeared to be locally abundant (i.e., represented by ten or more individuals captured at one or two sites) but were not widespread were *E. aestivalus, Notemigonus crysoleucas,* and *Rhinichthys atratulus.*

Many species were collected at only one or two sites (Table 2) and were represented by few individuals. Species taken during this survey that are likely to be truly rare in the Tippecanoe River drainage are *Ichthyomyzon bdellium, N. buchanani, Etheostoma camurum, E. maculatum, P. copelandi, P. c. manitou,* and *P. shumardi.* Species represented by several individuals and at three or more sites during this study, which maintain only limited populations elsewhere in the Midwest, were *Hybopsis amblops, Etheostoma pellucidum, E. tippecanoe,* and *Percina evides.*

Following is a synopsis of regional distribution and habitat information on uncommon fishes that occur in the Tippecanoe River. The capture site number and the number

Table 2. Fish species collected in the Tippecanoe River, Indiana, between 12 July 1985 and 20 September 1987. Site number is followed by number of individuals vouchered (in parenthesis) and is identified in Table 1.

| TAXA | SITE NUMBER (NUMBER OF VOUCHERED INDIVIDUALS) |
|---|---|
| **PETROMYZONTIDAE** | |
| *Ichthyomyzon bdellium* | 12(1), 15(1) |
| **CLUPEIDAE** | |
| *Dorosoma cepedianum* | 8(12), 10(1), 12(1), 13(1), 18(5), 20(1) |
| **UMBRIDAE** | |
| *Umbra limi* | 8(4) |
| **ESOCIDAE** | |
| *Esox americanus* | 8(1), 13(1), 14(2), 18(2) |
| **CYPRINIDAE** | |
| *Campostoma anomalum* | 6(4), 8(1), 9(2), 10(1), 12(2), 17(1), 18(1) |
| *Cyprinella spiloptera* | 3(2), 5(12), 6(25), 7(93), 8(39), 9(1), 10(16), 11(51), 12(115), 13(12), 14(27), 15(61), 16(52), 17(35), 18(10), 19(75), 20(26), 21(3), 22(14) |
| *Ericymba buccata* | 11(1), 12(1), 17(2), 18(7) |
| *Erimystax dissimilis* | 6(1), 11(4), 12(2), 15(1), 17(1), 18(3), 19(1), 20(1), 21(31), 22(2) |
| *Extrarius aestivalis* | 22(10) |
| *Hybopsis amblops* | 11(1), 12(4), 15(1), 16(2), 17(4), 18(5), 22(1) |
| *Luxilus chrysocephalus* | 1(1), 2(12), 3(2), 6(2), 7(7), 8(1), 9(1), 11(4), 12(4), 15(1), 18(2), 19(3), 20(6) |
| *Nocomis biguttatus* | 5(1), 6(1), 8(1), 10(2), 12(3), 14(5), 16(3), 18(1), 20(1) |

| TAXA | SITE NUMBER (NUMBER OF VOUCHERED INDIVIDUALS) |
|---|---|
| *N. micropogon* | 1(5), 3(4), 4(1), 5(1), 6(7), 7(12), 9(1), 10(2), 11(9), 12(14), 14(2), 15(16), 16(1), 18(1), 19(6), 20(3), 22(4) |
| *Notemigonus crysoleucas* | 1(13), 7(1) |
| *Notropis atherinoides* | 10(2), 12(1), 17(1), 18(2), 20(5), 22(1) |
| *N. buchanani* | 19(1) |
| *N. ludibundus* | 6(39), 7(13), 8(37), 9(11), 10(17), 11(12), 12(34), 14(5), 15(8), 16(10), 17(44), 19(3), 20(34), 22(2) |
| *N. rubellus* | 5(1), 6(16), 7(2), 10(1), 11(4), 12(1), 14(1), 17(1), 18(1), 20(39) |
| *N. volucellus* | 18(5) |
| *N. ludibundus* x *H. amblops* | 11(1), 19(1) |
| *Phenacobius mirabilis* | 12(1) |
| *Pimephales notatus* | 2(4), 3(3), 4(10), 5(4), 6(8), 7(8), 8(4), 10(2), 11(6), 12(12), 13(4), 14(2), 15(19), 16(17), 17(9), 18(4), 19(2), 20(3) |
| *Rhinichthys atratulus* | 8(11), 20(2) |
| *Semotilus atromaculatus* | 1(3), 6(15), 7(35), 8(8), 9(8), 10(2), 11(17), 12(1), 18(3), 19(2) |
| **CATOSTOMIDAE** | |
| *Carpiodes cyprinus* | 12(1) |
| *Catostomus commersoni* | 1(1), 6(6), 7(8), 8(7), 10(1), 11(8), 12(6) |
| *Erimyzon sucetta* | 1(1) |
| *Hypentelium nigricans* | 1(1), 3(2), 5(2), 6(3), 7(2), 8(3), 9(1), 11(5), 12(6), 17(1), 18(1), 20(1), 22(2) |
| *Ictiobus bubalus* | 17(2) |

| TAXA | SITE NUMBER (NUMBER OF VOUCHERED INDIVIDUALS) |
|---|---|
| *Minytrema melanops* | 8(13), 13(1), 15(2), 17(1), 18(1) |
| *Moxostoma erythrurum* | 18(1) |
| **ICTALURIDAE** | |
| *Ameiurus natalis* | 2(1), 3(3), 5(1), 6(1), 9(2), 18(1) |
| *Ictalurus punctatus* | 6(1) |
| *Noturus eleutherus* | 7(1), 12(1), 18(1), 22(6) |
| *N. flavus* | 5(8), 6(3), 7(6), 9(4), 11(3), 12(2), 15(3), 16(1), 19(2), 22(1) |
| *N. gyrinus* | 4(1) |
| *N. miurus* | 8(5), 9(2), 14(1) |
| *Pylodictis olivaris* | 20(1) |
| **FUNDULIDAE** | |
| *Fundulus notatus* | 4(2), 13(4) |
| **ATHERINIDAE** | |
| *Labidesthes sicculus* | 2(6), 8(1), 10(2), 13(2), 16(1), 18(2), 19(1) |
| **MORONIDAE** | |
| *Morone chrysops* | 18(2) |
| **CENTRARCHIDAE** | |
| *Ambloplites rupestris* | 2(1), 4(1), 5(3), 8(1), 9(2), 10(1), 12(1), 14(1), 15(1), 18(2), 19(3), 20(3), 22(1) |
| *Lepomis cyanellus* | 8(1), 9(2), 13(1), 18(1) |
| *L. gibbosus* | 5(4), 13(1), 20(1) |
| *L. gulosus* | 2(1), 4(1) |

| TAXA | SITE NUMBER (NUMBER OF VOUCHERED INDIVIDUALS) |
|---|---|
| *L. macrochirus* | 1(1), 3(1), 4(6), 5(2), 8(4), 9(1), 13(6), 21(1) |
| *L. megalotis* | 1(1), 2(6), 3(2), 4(2), 5(2), 7(1), 8(5), 9(3), 10(6), 12(1), 13(2), 14(1), 15(1), 16(4), 18(2), 20(2), 21(1) |
| *Micropterus dolomieu* | 18(2), 19(1), 22(1) |
| *M. salmoides* | 1(3), 2(1), 4(1), 5(1), 8(10), 9(1), 10(1), 13(2), 18(3), 20(2), 21(1) |
| *Pomoxis nigromaculatus* | 13(3) |
| **PERCIDAE** | |
| *Etheostoma blennioides* | 5(13), 6(4), 7(7), 8(24), 9(10), 10(13), 11(4), 12(4), 14(17), 15(6), 16(5), 17(1), 18(3), 19(3), 20(4), 22(2) |
| *E. caeruleum* | 2(14), 3(6), 5(1), 7(3), 9(2), 12(3), 14(1), 15(5), 16(1), 20(1) |
| *E. camurum* | 15(3), 17(3), 18(1) |
| *E. exile* | 2(1) |
| *E. flabellare* | 2(2), 3(2) |
| *E. maculatum* | 17(4) |
| *E. microperca* | 2(3), 4(1) |
| *E. nigrum* | 2(1), 4(2), 5(4), 6(2), 7(9), 8(13), 9(4), 10(4), 11(1), 12(4), 13(5), 14(6), 15(1), 17(2), 18(2), 20(12), 21(1) |
| *E. pellucidum* | 6(10), 8(5), 12(1), 17(1), 18(3), 20(7) |
| *E. spectabile* | 19(1) |
| *E. tippecanoe* | 14(2), 17(1), 18(1), 22(8) |
| *Perca flavescens* | 2(1), 4(1) |
| *Percina c. caprodes* | 3(2), 11(2), 12(10), 14(2), 15(2), 16(1), 17(1), 18(7), 19(1), 20(1) |

| TAXA | SITE NUMBER (NUMBER OF VOUCHERED INDIVIDUALS) |
|---|---|
| *P. c. manitou* | 3(3) |
| *P. copelandi* | 22(1) |
| *P. evides* | 5(6), 6(13), 7(7), 9(1), 10(2), 11(8), 12(2), 16(1), 18(2) |
| *P. maculata* | 2(3), 3(49), 5(3), 6(1), 8(8), 9(2), 10(3), 11(2), 12(4), 14(2) |
| *P. sciera* | 5(11),6(7),7(9),8(21),9(5),10(7),11(1),12(2),13(1), 16(3), 18(6),20(17) |
| *P. shumardi* | 21(2) |
| *P. caprodes* x *P. maculata* | 3(1) |
| **COTTIDAE** | |
| *Cottus bairdi* | 1(6),5(16),6(2),7(5),8(2),9(2),10(1),11(4),12(19), 14(3), 15(2), 16(1), 19(1), 20(5) |

of individuals vouchered are given in Table 2.

***Ichthyomyzon bdellium* (Jordan), Ohio lamprey.** *Ichthyomyzon bdellium* inhabits streams ranging from small creeks to big rivers. Smaller streams are utilized for spawning and provide habitat for ammmocoetes, which are found in pools and backwaters in mud and debris (Burr and Warren, 1986). The individuals collected during this survey were both adults.

Historically, *I. bdellium* has been recorded from the Tippecanoe River near Rochester, Fulton County (Hubbs and Trautman, 1937) and north of Winamac, Pulaski County (Gerking, 1945). The latter record represents the most recent capture of *I. bdellium* in Indiana (collected in 1944) prior to this study. Additional records for the species in Indiana are: Mud Creek, Cass County, Wabash drainage (Gerking, 1945); Lake Maxinkuckee outlet, Culver, Marshall County (Evermann and Clark, 1920); Wabash River, Terre Haute, Vigo County (Hubbs and Trautman, 1937); Whitewater River drainage, Wayne County (Plummer, 1851).

Hubbs and Trautman (1937) suggested that the Ohio lamprey and the chestnut lamprey (*Ichthyomyzon castaneus*) may intergrade in the lower Ohio River. Noting an overlap of characteristics, Burr (1980) arbitrarily identified parasitic lampreys in the upper and middle Ohio River and major tributaries as *I. bdellium* and lower Ohio forms as *I. castaneus.* Populations in the Ohio River bordering Indiana may represent intergrades of the two forms, although additional study is needed.

Table 3. Species reported historically from the Tippecanoe River but not collected during this survey.

| TAXA | SOURCE |
|---|---|
| *Ichthyomyzon fossor* | Gerking (1945), UMMZ |
| *Hiodon tergisus* | Evermann and Jenkins (1889) |
| *Esox lucius* | Gerking (1945) |
| *Cyprinus carpio* | Gerking (1945) |
| *Notropis chalybeus* | Gerking (1945) |
| *N. photogenis* | Gerking (1945), UMMZ |
| *Moxostoma carinatum* | Evermann and Jenkins (1889) |
| *M. duquesnei* | Gerking (1945) |
| *M. lacerum* | Evermann and Jenkins (1889) |
| *Ameiurus melas* | Gerking (1945) |
| *A. nebulosus* | Gerking (1945) |
| *Noturus exilis* | Evermann and Jenkins (1889) |
| *N. stigmosus* | Rohde (1980), UMMZ |
| *Lepomis microlophus* | Gerking (1945) |
| *Pomoxis annularis* | Gerking (1945) |
| *Stizostedion vitreum* | Blatchley (1938) |

Trautman (1981) presented evidence of the decline of this species in Ohio, where it is now protected (Johnson, 1987). *Ichthyomyzon bdellium* is considered to be extirpated in Illinois, where it apparently has been supplanted by *I. castaneus* in the Embarras and lower Wabash rivers (Starrett, *et al.*, 1960; Smith, 1979).

***Hybopsis amblops* (Rafinesque), bigeye chub.** Historic Tippecanoe River records for *H. amblops* were from Carroll County (Evermann and Jenkins, 1889); and Fulton County between Talma and Rochester in 1925 (UMMZ 66569), in 1938 (UMMZ 99951), and in 1941 (Gerking, 1945). Our collections of *H. amblops* throughout the middle and lower reaches of the Tippecanoe River indicate the presence of a sizeable population. Gerking (1945) and Nelson and Gerking (1968) considered *H. amblops* to occur in all major drainages in Indiana except the Kankakee River system. Clemmer (1980) reported a decidedly smaller range for the species in Indiana, with most records occurring in the upper half of the Wabash River system. Clemmer (1980) indicated no *H. amblops* records in the Whitewater River drainage and only one locality each in the White and Blue river drainages.

*Hybopsis amblops* has suffered dramatic declines since 1940 as a result of habitat modification in Illinois (Smith, 1979) and Ohio (Trautman, 1981). The species inhabits pools with moderate flow, raceways, and the bases of riffles in small to large streams, where clear water and firm sand or rocky substrates are present (Burr and Warren, 1986). *Hybopsis amblops* is protected in Illinois (Illinois Endangered Species Protection Board, 1990) and Michigan (Johnson, 1987). The present range of *H. amblops* in Indiana deserves further study because of population declines noted in adjacent States, where the species historically was common.

***Notropis buchanani* (Meek), ghost shiner.** *Notropis buchanani* is characteristic of low-gradient sections of large creeks and rivers having moderate flow and moderately clear to turbid water. It inhabits larger pools and protected backwaters without noticeable current (Gilbert, 1980) over a bottom of mixed sand, mud, and silt (Burr and Warren, 1986). Although *N. buchanani* occupies an expansive range in the United States, the species' occurrence east of the Mississippi River appears to be sporadic and localized (Gilbert, 1980).

In Indiana, *N. buchanani* was previously known only from the Ohio and lower White Rivers (Gerking, 1945). Our record from the Tippecanoe River represents a substantial range extension to the upper Wabash drainage of northern Indiana.

***Etheostoma camurum* (Cope), bluebreast darter.** *Etheostoma camurum* is sporadically distributed and absent in many rivers within its range in the eastern United States. The species occupies fast riffles of large, clear streams at a preferred depth of 10 to 30 cm. Adults are almost always found near large boulders (Page, 1983).

Historic documentation of *E. camurum* in the Tippecanoe River includes records from the middle (Fulton County; Jordan, 1889) and lower (Carroll County; Evermann and Jenkins, 1889) reaches. A museum record for *E. camurum* (UMMZ 187513) from Fulton County by B.W. Evermann was probably from the late 1800s and may represent the same record cited by Jordan (1889). Additional records for the Tippecanoe River were from Fulton County in 1925 (UMMZ 66565 and 66602). Gerking (1945) collected *E. camurum* in this vicinity during his survey of Indiana fishes.

Our collection sites for *E. camurum* (Sites 15 and 18) and Tom Simon's collection site (Site 17) were all from the middle reaches of the river in Pulaski County. From these data, it appears that the range of *E. camurum* in the Tippecanoe River has diminished, and the few specimens collected indicate that the population is small. *Etheostoma camurum* is generally distributed throughout the Wabash-Ohio drainage of Indiana. However, only in the Big Blue River (Ohio drainage) is there evidence of a large population (Whitaker and Gammon, 1988). The species is listed as endangered in Indiana (Indiana Department of Natural Resources, 1990) and is also protected in Illinois (Illinois Endangered Species Protection Board, 1990).

***Etheostoma maculatum* Kirtland, spotted darter.** Three subspecies of *E. maculatum* were recognized by Zorach and Raney (1967). Page (1985) and Etnier and

Williams (1989) demonstrated that *E. maculatum* is specifically distinct from the southern forms, now known as *E. sanguifluum* and *E. vulneratum,* and has a much smaller range than previously thought. *Etheostoma maculatum* occurs sporadically in a few tributaries of the Ohio River system (Page, 1983). The habitat of *E. maculatum* was described by Zorach and Raney (1967) as swift riffles of medium to large streams.

*Etheostoma maculatum* is extremely rare in Indiana. Zorach and Raney (1967) examined two specimens collected by P. Kirsch on 25 August 1899 from the Tippecanoe River at "Marshland", Fulton County, Indiana. Jordan (1889) reported an earlier collection of four specimens from the "Marshland" locality and a single specimen from Deer Creek, a Wabash River tributary at Camden, Carroll County, Indiana. Tom Simon's collection of four *E. maculatum* at Site 17 indicates that the species is extant but rare in the Tippecanoe River. Baker, *et al.* (1985) reported the recent collection of over 32 specimens of *E. maculatum* in the Blue River,a tributary of the Ohio River in Washington, Crawford, and Harrisburg Counties in southern Indiana.

*Etheostoma maculatum* is endangered in Indiana (Indiana Department of Natural Resources, 1990) and is also protected in Kentucky (Warren, *et al.,* 1986) and Ohio (Johnson, 1987).

***Etheostoma pellucidum* (Putnam), eastern sand darter.** Gerking (1945) collected *E. pellucidum* at four localities in the middle Tippecanoe River in Marshall, Fulton, and Pulaski Counties, Indiana and reported one literature record in the lower river in Carroll County. Earlier Tippecanoe River records are from Fulton County between Talma and Rochester in 1925 (UMMZ 66562, 12 specimens) and near Rochester in 1938 (UMMZ 99936, 59 specimens). Our 1987 collection at the latter locality (Site 8) yielded only five individuals and may indicate a decline in *E. pellucidum* populations in the Tippecanoe River. Statewide, this species has been reported from scattered localities in large- and medium-sized streams in the Wabash, Maumee, White, and Ohio drainages (Gerking, 1945).

Habitat loss due to excessive siltation of sandy streams has led to declines in habitat for *E. pellucidum* throughout much of its range, thus the species may deserve Federal protection (Johnson, 1987). This species is protected in Illinois (Illinois Endangered Species Protection Board, 1990), Ohio, and Michigan (Johnson, 1987) and is of special concern in Indiana (Indiana Department of Natural Resources, 1990) and Kentucky (Warren, *et al.,* 1986).

***Etheostoma tippecanoe* Jordan and Evermann, Tippecanoe darter.** *Etheostoma tippecanoe* was described by Jordan and Evermann (1891) from specimens collected in the Tippecanoe River at "Marshland", Fulton County, Indiana. The only additional recorded locality for this species from the Tippecanoe River prior to this study was from Fulton County in 1925 (UMMZ 66560). Elsewhere in Indiana, specimens have been collected from the East Fork White River, Martin County (Gerking, 1945) in 1936 and 1942. Our recent attempts to collect *E. tippecanoe* at known East Fork White River localities were unsuccessful.

The results of this study indicate that *E. tippecanoe* is presently restricted in Indiana to long, gravel and rubble riffles along the middle Tippecanoe River and in the lower river just below Lake Freeman. The species occurred only sporadically in the middle Tippecanoe River but was common just below Lake Freeman, presumably as a result of reduced suspended sediments in waters released from the dam.

*Etheostoma tippecanoe* is endangered in Indiana (Indiana Department of Natural Resources, 1990), is protected in Ohio (Johnson, 1987), and is of special concern in

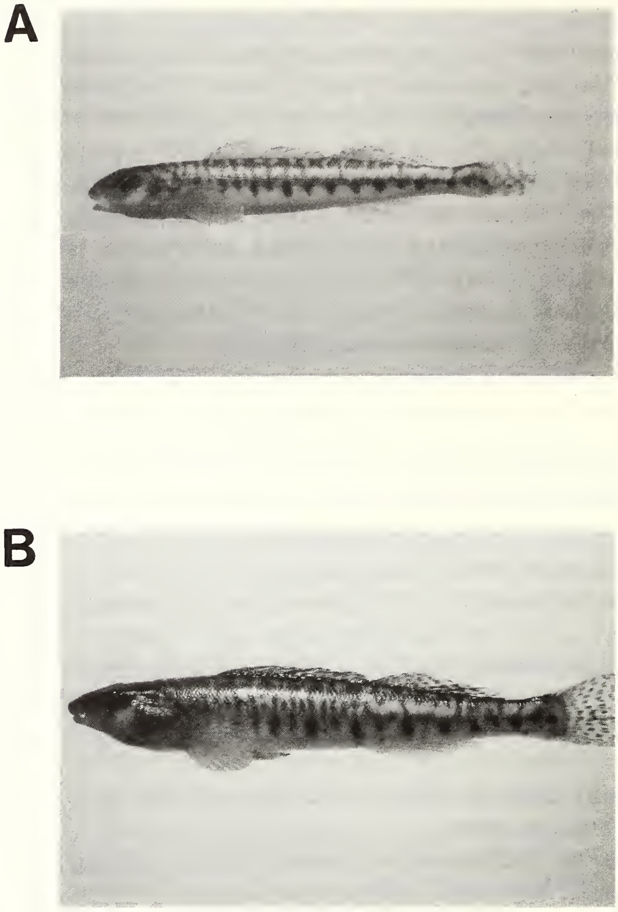

Figure 2. **A.** *Percina caprodes manitou.* 86-mm SL female collected in Lake Wawasee, Kosciusko County, Indiana, 7 September 1985. **B.** *P. c. caprodes* x *P. c. manitou,* 115-mm SL male, Tippecanoe River, Kosciusko County, Indiana, 7 September 1985.

Kentucky (Warren, *et al.,* 1986).

***Percina caprodes manitou* (Jordan), Indiana logperch.** Our sampling efforts in the upper Tippecanoe River produced a form of logperch which we believe to be a valid but currently unrecognized subspecies of *Percina caprodes.* This form is found in the glacial lakes region of northern Indiana and possibly further north.

The taxonomy of logperches in Indiana has a confused history. Two subspecies (*P. c. caprodes* and *P. c. semifasciata*) of logperch are known to occur in the State (Gerking, 1945). Two other nominal forms of logperches were described from the glacial lakes of northern Indiana but subsequently were not recognized, because one form was considered to be a synonym of *P. caprodes* and one was considered to be based on hybrids. These were, respectively, *Percina manitou* Jordan 1877, from Lake Manitou, Fulton County, and *Hadropterus evermanni* Moenkhaus 1903, from Lake Tippecanoe, Tippecanoe County.

*Hadropterus evermanni* was considered by Hubbs (1926) and Collette and Knapp (1966) to be based on hybrids of *P. c. semifasciata* and *P. maculata.* We examined two paratypes of *Hadropterus evermanni* (USNM 50834, 126919). Characteristics of the poorly preserved specimens (both females) were: lateral line scales 81-82; pored scales on the caudal fin 0-2; modified scales between pelvic fins 1-2; nape squamation 50-80%; belly midline squamation 0-30% (scales located posteriorly); black basicaudal spot present; and snout not produced or slightly produced. One specimen had 13 vertically elongate blotches along the side and the other had rounded dark blotches. We agree with earlier conclusions that *Hadropterus evermanni* is based on *P. caprodes* X *P. maculata* hybrids.

*Percina manitou* was considered by Collette and Knapp (1966) to be a synomym of *P. c. semifasciata* and gave the following counts for the lectotype (USNM 23458): lateral line scales 86, dorsal spines 15, dorsal rays 14, and anal rays 11. Our examination of the poorly preserved lectotype, a female, revealed these additional characteristics: modified scales between pelvic fins 1 (but also with 2 scars where scales had been); nape and belly midline unscaled; black basicaudal spot present; and snout produced.

We currently believe, based on material collected in 1985 and additional museum specimens examined (UMMZ 55876, 56443, 63049, 66606, 81496, 81864, 81972, 89990, 98617, 101956, 112042, 132283, 160792, 162977, 194604, 213163, 213165, and 213168), that the form described by Jordan (1877) is a distinct taxon, *Percina caprodes manitou.* This conclusion is based on the fact that *P. c. manitou* (Figure 2A) is morphologically distinguishable from both *P. c. caprodes,* which occurs south of the range of *P. c. manitou,* and from *P. c. semifasciata,* which occurs to the north. It appears to be intergrading with *P. c. caprodes* in the upper Tippecanoe River (Figure 2B) and thus is not considered a full species.

Available data suggesting that the Indiana logperch is a subspecies of *P. caprodes* include the following:

1. The pigmentation pattern is unique. The vertical bars on the side tend to anastomose on the back, forming dark circles. Also, the bars are interrupted on the posterior half of the body, creating a light longitudinal stripe along the posterior half of the upper side. In both *P. c. caprodes* and *P. c. semifasciata,* the bars continueuninterrupted over the back to join those of the other side.
2. The nape is unscaled and the belly is unscaled or barely scaled. *Percina c. caprodes* in the Tippecanoe River usually (93%, N = 14) has a partly or fully scaled nape and partly to fully scaled belly. Intergrades in the upper Tippecanoe River (near North Webster, N = 3) have a partly or fully scaled nape but an unscaled to partly scaled belly and thus are intermediate between *P. c. manitou* and *P. c. caprodes.*

Although museum specimens have sometimes been labelled as such, we do not consider it tenable to conclude that *P. c. manitou* is an $F_1$ hybrid between *P. caprodes* and *P. maculata.* The large number of individuals involved make that extremely unlikely and, more importantly, on 7 September 1985, we collected true hybrids in the Tippecanoe River (INHS 69039; 1 specimen, 2 frozen) between *P. caprodes* and *P. maculata.* The hybrids were not similar in morphology to *P. c. manitou* but instead were intermediate between *P. c. manitou* and *P. maculata.* They had the light longitudinal stripe along the posterior half of the upper side and dark vermiculations on the nape as in *P. c. manitou,* but also had large oval black blotches along the side of the body and a short snout as in *P. maculata.*

The range of *P. c. manitou* is presently unknown. It occurs in lakes in the upper Tippecanoe River system, in adjacent tributaries of the St. Joseph River system (Lake Michigan drainage), and probably extends into the State of Michigan.

***Percina copelandi* (Jordan), channel darter.** *Percina copelandi* occurs in pools of large streams and along lake shores where there is sufficient current to maintain a bottom of sand or sand mixed with gravel or rocks (Page, 1983; Burr and Warren, 1986). Our capture of one specimen represents the first record of *P. copelandi* from the Tippecanoe River. Gerking (1945) recorded the species from the Wabash River, Warren County, Indiana and one of its tributaries (Big Pine Creek) in Fountain County. Page (1983) mapped five additional records for *P. copelandi* in the Wabash River, spread along most of its length, and two records in the upper and middle reaches of the West Fork White River. The occurrence of *P. copelandi* in the lower Tippecanoe River and Wabash River may be underrepresented. However, further investigation of the species' status is warranted. This species is protected in Michigan and Ohio (Johnson, 1987).

***Percina evides* (Jordan and Copeland), gilt darter.** *Percina evides* lives in riffles of clean, small- to medium-sized rivers. Larger individuals inhabit larger and faster riffles, often over rubble. Smaller individuals are in smaller, gravel riffles (Page, 1983). The species is now extirpated or uncommon in many areas, where it previously existed in large populations. Stream degradation has severely reduced the range of *P. evides,* and it has been extirpated from Ohio (Trautman, 1981) and Illinois (Smith, 1979).

Historic Tippecanoe River records were from the late 1800s and early 1900s in Fulton County (UMMZ 61577, 66561, 167077, and 213115). Since 1900, a drastic reduction in the abundance and range of *P. evides* in Indiana has been noted (Gerking, 1945; Nelson and Gerking, 1968). Gerking's (1945) Statewide survey did not produce this species, though he sampled five of the 11 known Indiana localities, and six Tippecanoe River sites in the range of our *P. evides* collections. Margulies, *et al.* (1980) collected a single specimen in 1977 from the West Fork White River, Morgan County. The collection represented only the second record for this species in Indiana in this century and the first record in 52 years. Our capture of 59 specimens at nine sites indicates that a good population of *P. evides* is present in the upper and middle Tippecanoe River. This species is endangered in Indiana (Indiana Department of Natural Resources, 1990) and is of special concern in Kentucky (Warren, *et al.,* 1986).

***Percina shumardi* (Girard), river darter.** *Percina shumardi* has not been previously reported from the Tippecanoe River. The nearest known locality was the Wabash River, Carroll County, upstream of the confluence with the Tippecanoe River, which was reported as a literature record by Gerking (1945). Additional Indiana records are from the West Fork White River, Marion County; East Fork White River, Martin County; and from scattered localities along the middle and lower Wabash River (Gerking, 1945; Whitaker and Wallace, 1973). The species is also known to occur in the main channel of the Ohio River along the Indiana border (Burr and Warren, 1986).

The habitat of *P. shumardi* is moderate to fast current over rocks or gravel in medium to large rivers (Page, 1983). The difficulty of sampling this habitat probably accounts for the paucity of records for *P. shumardi* in Indiana. *Percina shumardi* is protected in Ohio (Johnson, 1987).

## THE TIPPECANOE RIVER AS AN AQUATIC ECOSYSTEM

The fish fauna of the Tippecanoe River is diverse and includes a number of species that are rare or declining throughout their historic ranges. Cummings and Berlocher (1990) presented evidence that the unionid mollusk fauna of the Tippecanoe River is among the richest in the upper Midwest. Despite the fact that the watershed is primarily composed of erodable agricultural land and the river system has been subjected to channelization, urban development, and mainstem impoundment, the Tippecanoe River retains a variety of instream habitats and water of sufficient quality to support a rich aquatic fauna. The aquatic fauna appears to have been less adversely affected by habitat modification than is commonly observed in other Midwestern streams (Smith, 1971; Cummings and Berlocher, 1990). We hypothesize that the predominance of sandy soils in the watershed and sediment retention by lakes in the drainage have reduced the degree of turbidity and silt deposition responsible for the decline of many fish species in the Wabash River drainage (Smith, 1971). Unlike many Midwestern streams, the Tippecanoe River continues to support a rich and diverse biota and it should be protected from adverse development. Protection of the middle reach of the Tippecanoe River (between sample sites 13 and 18) is of particular importance due to the presence of the greatest variety of rare fishes in this segment.

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## LITERATURE CITED

Baker, C.D., B.J. Forsyth, T. Wiles, and D.B. Abrell. 1985. Rediscovery of the spotted darter, *Etheostoma maculatum,* in Indiana waters: Blue River; Crawford, Harrison and Washington Counties; Ohio River drainage, USA. Proc. Indiana Acad. Sci. 94: 603-605.

Blatchley, W.S. 1938. The fishes of Indiana. Nature Publ. Co., Indianapolis, Indiana, 121 pp.

Burr, B.M. 1980. A distributional checklist of the fishes of Kentucky. Brimleyana 3: 53-84.

__________ and M.L. Warren, Jr. 1986. A distributional atlas of Kentucky fishes. Kentucky Natur. Pres. Comm. Sci. Tech. Ser. No. 4, 398 pp.

Clemmer, G.H. 1980. *Hybopsis amblops* (Rafinesque), bigeye chub. *In:* D.S. Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. (Eds.), *Atlas of North American Freshwater Fishes,* p. 181, North Carolina State Mus. Natur. Hist., Raleigh, North Carolina, 854 pp.

Collette, B.B. and L.W. Knapp. 1966. Catalog of type specimens of the darters (Pisces, Percidae, Etheostomatini). Proc. U.S. Nat. Mus. 119(3550): 1-88.

Cummings, K.S. and J.M.K. Berlocher. 1990. The naiades or freshwater mussels (Bivalvia: Unionidae) of the Tippecanoe River, Indiana. Malacological Rev. 23: 83-98.

Eigenmann, C.H. and C.H. Beeson. 1894. Fishes of Indiana. Proc. Indiana Acad. Sci. 9: 76-108.

Etnier, D.A. and J.D. Williams. 1989. *Etheostoma* (*Nothonotus*) *wapiti* (Osteichthyes: Percidae), a new darter from the southern bend of the Tennessee River system in Alabama and Tennessee. Proc. Biol. Soc. Washington 102: 987-1000.

Evermann, B.W. and H.W. Clark. 1920. Lake Maxinkuckee, a physical and biological survey. Indiana Dep. Conserv., Indianapolis, Indiana, 660 pp.

__________ and O.P. Jenkins. 1889. Notes on Indiana fishes. Proc. U.S. Nat. Mus. 11(1888): 43-58.

Gerking, S.D. 1945. The distribution of the fishes of Indiana. Invest. Indiana Lakes Streams 3: 1-137.

Gilbert, C.R. 1980. *Notropis buchanani* Meek, ghost shiner. *In:* D.S. Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. (Eds.), *Atlas of North American Freshwater Fishes,* p. 243, North Carolina State Mus. Natur. Hist., Raleigh, North Carolina, 854 pp.

Hay, O.P. 1894. The lampreys and fishes of Indiana. 19th Ann. Rep. Indiana Dep. Geol. Natur. Res., pp. 146-296.

__________. 1902. The lampreys and fishes of Indiana. Bienn. Rep. Indiana Comm. Fish Game 1902: 62-119.

Homoya, M.A., D.B. Abrell, J.R. Aldrich, and T.W. Post. 1985. The natural regions of Indiana. Ecology 94: 245-268.

Hubbs, C.L. 1926. A check-list of the fishes of the Great Lakes and tributary waters, with nomenclatorial notes and analytical keys. Univ. Michigan Mus. Zool. Misc. Pub. 15, 77 pp.

__________ and M.B. Trautman. 1937. A revision of the lamprey genus *Ichthyomyzon.* Misc. Pub. Mus. Zool. Univ. Michigan 35: 1-109.

Indiana Department of Natural Resources. 1990. Indiana's rare plants and animals, a checklist of endangered and threatened species. Indiana Dep. Natur. Res., Indianapolis, Indiana, 36 pp.

Illinois Endangered Species Protection Board. 1990. Checklist of endangered and threatened animals and plants of Illinois. Illinois Endangered Species Protection Board, Springfield, Illinois, 26 pp.

Jenkins, R.E. 1980. *Lagochila lacera* Jordan and Brayton, harelip sucker. *In:* D.S. Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. (Eds.), *Atlas of North American Freshwater Fishes,* p. 407, North Carolina State Mus. Natur. Hist., Raleigh, North Carolina, 854 pp.

Johnson, J.E. 1987. Protected fishes of the United States and Canada. Amer. Fish. Soc., 42 pp.

Jordan, D.S. 1877. On the fishes of northern Indiana. Proc. Acad. Natur. Sci. Philadelphia 29: 42-82.

__________. 1889. Report of explorations made during the summer and autumn of 1888, in the Alleghany region of Virginia, North Carolina and Tennessee, and in western Indiana, with an account of the fishes found in each of the river basins of those regions. Bull. U.S. Fish Comm. 8(1888): 97-173.

__________ and B.W. Evermann. 1891. Description of a new species of fish from Tippecanoe River, Indiana. Proc. U.S. Nat. Mus. 13(1890): 3-4.

Margulies, D., O.S. Burch, and B.F. Clark. 1980. Rediscovery of the gilt darter (*Percina evides*) in the White River, Indiana. Amer. Midl. Natur. 104: 207-208.

Moenkhaus, W.J. 1903. Description of a new species of darter from Tippecanoe Lake. Bull. U.S. Fish Comm. 22(1902): 397-398.

Nelson, J.S. and S.D. Gerking. 1968. Annotated key to the fishes of Indiana. Dep. Zool., Indiana Univ., Bloomington, Indiana, 84 pp.

Page, L.M. 1983. Handbook of darters. T.F.H. Publ. Inc., Neptune City, New Jersey, 271 pp.

__________. 1985. Evolution of reproductive behaviors in percid fishes. Illinois Natur. Hist. Surv. Bull. 33: 275-295.

__________ and B.M. Burr. 1991. A field guide to freshwater fishes of North America north of Mexico. Peterson Field Guide Series, Houghton Mifflin Company, Boston, Massachusetts, 432 pp.

Plummer, J.T. 1851. List of fishes found in the vicinity of Richmond, Indiana. Proc. Bost. Soc. Natur. Hist. 3(1848-51): 53-55.

Rohde, F.C. 1980. *Noturus stigmosus* Taylor, northern madtom. *In:* D.S. Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. (Eds.), *Atlas of North American Freshwater Fishes,* p. 469, North Carolina State Mus. Natur. Hist., Raleigh, North Carolina, 854 pp.

Smith, P.W. 1971. Illinois streams: A classification based on their fishes and an analysis of factors responsible for disappearance of native species. Illinois Natur. Hist. Surv. Biol. Notes 76, 14 pp.

__________. 1979. The fishes of Illinois. Univ. Illinois Press, Urbana, Illinois, 314 pp.

Starrett, W.C., W.J. Harth, and P.W. Smith. 1960. Parasitic lampreys of the genus *Ichthyomyzon* in the rivers of Illinois. Copeia 1960: 337-346.

Trautman, M.B. 1981. The fishes of Ohio. Ohio St. Univ. Press, Columbus, Ohio, 782 pp.

Warren, M.L., Jr., W.H. Davis, R.R. Hannan, M. Evans, D.L. Batch, B.D. Anderson, B. Palmer-Ball, Jr., J.R. MacGregor, R.R. Cicerello, R. Athey, B.A. Branson, G.J. Fallo, B.M. Burr, M.E. Medley, and J.M. Baskin. 1986. Endangered, threatened, and rare plants and animals of Kentucky. Trans. Kentucky Acad. Sci. 47: 83-98.

Whitaker, J.O., Jr. and J.R. Gammon. 1988. Endangered and threatened vertebrate animals of Indiana their distribution and abundance. Indiana Acad. Sci. Monogr. 5, 122 pp.

__________ and D.C. Wallace. 1973. Fishes of Vigo County, Indiana. Proc. Indiana Acad. Sci. 82: 448-464.

Wright, H.P. 1932. Aquatic Mollusca of the Tippecanoe River system Part 1. Post-glacial migration and present distribution of four species of snails. Ecol. Monogr. 2: 233-259.

Zorach, T. and E.C. Raney. 1967. Systematics of the percid fish, *Etheostoma maculatum* Kirtland, and related species of the subgenus *Nothonotus*. Amer. Midl. Natur. 77: 296-322.

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# THE LEWIS MASTODONT (*MAMMUT AMERICANUM*) LOCALITY, WABASH COUNTY, NORTH-CENTRAL INDIANA

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ABSTRACT: The remains of an adult mastodont (*Mammut americanum*) were unearthed by highway construction crews in 1990 while they were working on Meridian Road in northern Wabash County, Indiana. The remains occurred in a peat deposit at a depth of about two meters. Peat and clay excavated from the site were deposited in a nearby field, where our recovery efforts were concentrated. The bones were extensively damaged by the heavy construction equipment. The amount of skeletal material removed during construction is unknown, but portions of approximately 40 percent of the skeleton were retrieved. Radiocarbon dating of the mastodont bone indicated an age of 11,160 B.P. Analysis of pollen from the tusk cavity indicated that an open, spruce-dominated woodland covered the region at the time of deposition.

## INTRODUCTION

On 17 September 1990, a highway construction crew working on Meridian Road 4.2 km northwest of North Manchester discovered a large tooth in the earth being removed from the roadway. The project was located approximately 300 m south of the Wabash/Kosciusko County line (SW$^1/_4$, NW$^1/_4$, NW$^1/_4$, Sec. 19, T30N, R7E, North Manchester North Quadrangle). Approximately 16,000 cubic meters of excavated roadway material was transported by truck to a field on the Lewis farm about 1.6 km south of the deposit. The material included asphalt chunks from the road, logs from the original corduroy road, previously transported road bed materials, as well as peat and clay removed in widening the roadway. Among these materials, unknown to the construction crew, were interspersed the remains of a mastodont. With news of the tooth discovery, Mrs. Bud Lewis contacted archaeologists at Ball State University, who in turn referred her to the junior author (R.L.R.) at the Indiana State Museum. With permission from the Lewis family, Richards and volunteers surveyed the refuse heaps on September 21, recovering portions of several proboscidean ribs. Richards in turn contacted Luke Hunt, a science teacher at nearby Whitko High School, who then directed the effort to recover the dispersed skeleton and any other pertinent associated materials.

The project geotechnical report (Butler, Fairman, and Seufert, Inc.) indicated the following stratigraphy at sounding PS-14 near the site: topsoil (0-19 cm), peat and clay (20-136 cm), sand (137-155 cm). The level at which the mastodont remains occurred is uncertain, but the remains are thought to have been encountered in peats and clays at a depth of about 2 m.

The mastodont locality lies within the southern margin of a belt of hills and kettle holes historically referred to as the "Packerton moraine" (Wayne and Thornbury, 1951). The Packerton feature is a recessional edge moraine of Trafalgar ice (East White sublobe, Huron-Erie Lobe, Wisconsinan glaciation; Bleuer and Melhorn, 1989; Gray, 1989). The Packerton was once thought to be a terminal moraine of the northeastern source Saginaw lobe (Wayne and Thornbury, 1951; Schneider and Johnson, 1967), which now appears to have terminated further to the north. The stagnant ice topography of the Packerton feature was later blanketed by a thin veneer of Lagro sediments (often too thin regionally to show on Gray's 1989 glacial geology map). Lagro ice (Miami sublobe, Huron-Erie Lobe) advanced from its northeastern source into Wabash County sometime after the "Erie Interstade" (approximately 15,500 B.P.) and by approximately 14,800 B.P. had receded back to near the eastern Indiana border (Fort Wayne Moraine; Mickelson, *et al.*, 1983). After stagnation and melting of Lagro ice, marl and peat began accumulating in kettles and other basins. These sediments were deposited within the past 13,000 years and occasionally contain the remains of mastodonts and other extinct mammals (Wayne, 1963). The Lewis mastodont was deposited in one of these basins.

The American mastodont (*Mammut americanum*) was widespread throughout the United States during the Late Pleistocene (Kurtén and Anderson, 1980). Living animals stood between 2.7-3.0 m at the shoulder (males). They may have preferred to live in open spruce woodlands, lowlands, and swamps. Their diet may have included twigs and cones of conifers, leaves, coarse grasses, swamp plants, and mosses. The mastodont was extinct by 9,000 B.P. (Kurtén and Anderson, 1980).

Other published records of large Late Pleistocene mammals recovered from Wabash County include two specimens of both the American mastodont and the mammoth (*Mammuthus* sp.; Elrod and Benedict, 1892; Hay, 1912) and one specimen of the flat-headed peccary (*Platygonus compressus*; Cope and Wortman, 1884; Hay 1912). The remains of an elk (*Cervus elaphus*) were probably of Holocene age (Elrod and Benedict, 1892; Hay, 1912). Additional unpublished mastodont finds have also occurred in Wabash County.

## METHODS

Retrieval efforts were undertaken from 20 September 1990 to 13 December 1990. Help came from teachers, college students, high school, middle school, and elementary school students, parents, and other interested individuals. Because the original site was under development (as well as under water), the recovery effort focused upon the excavated peat and clay on the Lewis farm. The search involved the use of shovels, rakes, hoes, hand spades, and tile probes. Most pieces of the skeleton were recovered during the removal of small increments of sediment from a vertical bank face while digging horizontally through select piles. Probing was ineffective. Cleaning and preservation were conducted at Whitko High School. Bone materials were washed and brushed under tap water, and slowly dried in plastic bags ventilated with small holes. Drying required two to three months. The bones did display some warping and checking as a result of drying. Dried bones were then coated with Vinac B-15 dissolved in alcohol to a consistency of syrup. The teeth were consolidated with glyptal (driven with acetone) under vacuum at the Indiana State Museum.

A section of mastodont rib (640 g) was submitted to the Illinois State Geological Survey for radiocarbon dating. A sample of sediment from deep within the tusk cavity was submitted to Donald Whitehead, Department of Biology, Indiana University, for pollen analysis.

## RESULTS

The teeth (Figures 1 and 2) and some postcranial bones clearly identified the specimen as an American mastodont (*Mammut americanum*). A single individual was represented. The recovered inventory includes: 4 upper molars (L, R M2; L, R M3); 4 lower molars (L, R m2; L, R m3); portions of 2 tusks; small fragments of skull; portions of mandible; thyrohyoid; fragments of 8 thoracic vertebrae (including T-20); lumbar vertebrae L-1 and L-2; one caudal vertebra; portions of 7L and 12R ribs (including L #1; L, R #2; L, R #3 (or 4-6); L, R #7 (or 8-14); 10 rib heads; portions of L humerus (proximal articulation; distal articulation, separate medial and lateral condyle fragments); R metacarpal I; R femur, with fragmentary proximal end; R patella; R fibula, distal end; L astragalus; R ectocuneiforme; L, R mesocuneiformes; L, R entocuneiformes; L metatarsal (?) IV; R metatarsal I; R metatarsal IV; R metatarsal V; 5 phalanges; and 3 sesamoids. Portions of approximately 40% of the total skeletal elements were recovered. The scapulae, pelvis, and sternebrae were scarcely represented.

Tooth wear is roughly equivalent to that of a 36 year old African elephant (wear stage XXI of Laws, 1966). Lines of epiphyseal union are obliterated on all of the recovered long bone portions, indicating full attainment of adult stature. Measurements of the teeth, femur, and thyrohyoid are presented in Table 1.

A radiocarbon date on the total organic content of the mastodont rib produced an age of 11,160 ± 90 radiocarbon years B.P. (ISGS-2220). Analysis of the pollen from the tusk cavity suggests the existence of an open, spruce-dominated woodland at the time of deposition (D.R. Whitehead, pers. comm.). Pollen of fir, larch, and some hardwoods (especially ash and hornbeam) were also present. Herbs totaled 33% of the counted sample, represented primarily by sedges, composites, and grasses. The presence of algae, water milfoil, and cattails indicate open water at the site.

Other biotic remains recovered from the peat and clay piles included mollusks and bones of several smaller vertebrates. Species collected by hand included such terrestrial snails (primarily from peat) as *Anguispira alternata, Triodopsis multilineata, Triodopsis* cf. *T. vulgata,* and *Mesodon inflectus* and such aquatic snails (primarily from clayey sediments) as *Heliosoma anceps anceps, Gyraulus deflectus, Planorbella campanulata campanulata,* and *Valvata tricarinata tricarinata.* Some unidentified sphaerid clams were also found. Several minute species of aquatic snails were also abundant in the clayey soils. The smaller vertebrate skeletal remains included specimens of the following: duck, undet. small sp., L, R humeri; *Castor canadensis* (beaver), R dentary; *Sciurus niger* (fox squirrel), R femur; *Procyon lotor* (raccoon), R dentary, R tibia, R humerus; and cervidae cf. *Odocoileus virginianus* (white-tailed deer), R tibia, proximal phalange. Bones of a domestic sheep/goat and chicken were intermingled with the other bones. The duck, beaver, and deer remains had the same dark brown coloration as the mastodont bones. The other remains did not exhibit this coloration. Because of the disturbed nature of the soils any association between the mollusks, mastodont, and other vertebrates is speculative.

The mastodont remains and other materials from the locality are housed at Whitko High School, South Whitley, Indiana, under catalogue numbers LM-90-0.0 to LM-90-11.1.

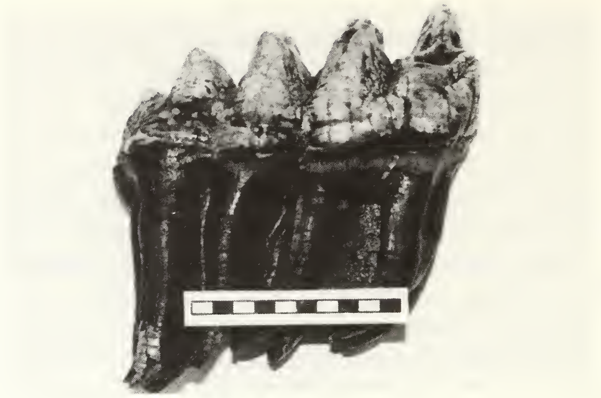

Figure 1. Lewis mastodont (*Mammut americanum*), Lower R molar 3 (right lateral view). Tooth wear at death was roughly equivalent to 36 years of the modern African elephant. Scale in centimeters.

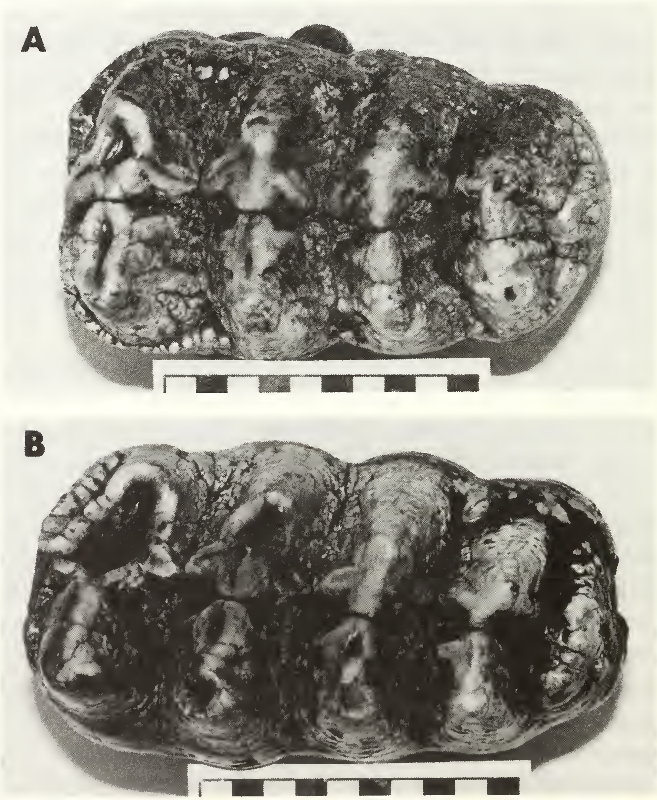

Figure 2. Lewis mastodont (*Mammut americanum*), select teeth. A. Upper RM3, crown view. B. Lower Rm3, crown view. Scale in centimeters. Note that the cusps of the upper crown align perpendicular to the long axis of the tooth, while those of the lower are oblique.

Table 1. *Mammut americanum* tooth, femur, and thyrohyoid measurements, Lewis Mastodont, Wabash County, Indiana (mm).

**Teeth**

| Placement | Length | Width | Protoloph(-id) | Metaloph(-id) | Tritoloph(id) | Tetartoloph(-id) |
|---|---|---|---|---|---|---|
| Upper L M3 | 187.5 | 106.5 | 105.4 | 104.0 | 96.5 | 85.4 |
| Upper R M3 | 176.0 | 106.5 | 101.9 | 103.5 | 95.9 | 83.3 |
| Upper L M2 | 122.0 | 93.0 | 87.4 | 90.2 | 93.1 | |
| Upper R M2 | 121.0 | 89.5 | 86.8 | 91.1 | 91.0 | |
| Lower L m2 | 122.0 | 98.0 | 83.3 | 94.4 | 95.0 | |
| Lower R m2 | 117.0 | 98.5 | 80.0 | 93.1 | 93.2 | |
| Lower L m3 | 188.5 | 106.0 | 99.6 | 106.8 | 103.0 | 95.0 |
| Lower R m3 | 186.0 | 103.0 | 95.6 | 103.4 | 98.6 | 88.6 |

**Femur**

| | |
|---|---|
| Greatest length | 1108.0 |
| Greatest anteroposterior diameter of head | 169.0 |
| Least transverse diameter of shaft | 157.0 |
| Anteroposterior diameter of shaft at above position | 95.0 |
| Greatest transverse width of distal end (normal to articular surface) | 283.0 |
| Greatest width across condyles (normal to line drawn between posterior tips of condyles) | 250.0 |
| Least circumference of shaft | 418.0 |

**Thyrohyoid**

| | |
|---|---|
| Total length | 147.1 |

## DISCUSSION

How much of the skeleton remains buried below the construction site is unknown, but the relatively small area of sediment removed suggests that the bones lay in close proximity, if not in articulation.

The teeth are of medium size, when their measurements are compared with those from other Indiana (Graham, Holman, and Parmalee, 1983; Richards, 1984; Richards, Whitehead, and Cochran, 1988), Missouri (Saunders, 1977), and Michigan (Skeels, 1962) specimens. In particular, the third molars do not reach the great lengths displayed among the larger Michigan and Boney Springs, Missouri specimens. The femur is also of medium size, when compared to 8 other adult femora from Indiana and Missouri (Richards, 1984; Saunders, 1977).

The ratio of femur length (1.06 m) over total stature (2.78 m, height to tips of thoracic vertebrae between scapulae) of the Warren mastodont from New York (Osborn, 1936) to the length of the Lewis femur (1.108 m) indicates that the Lewis mastodont stood approximately 2.91 m (9’7") between the shoulder blades. Kurtén and Anderson (1980) note that mastodont shoulder height ranged between 2.7 and 3.0 m and that females were smaller than males (e.g., one specimen stood 2.3 m). Perhaps, the Lewis mastodont is a male.

The disassociated mollusks indicate that the basin once harbored an abundance of aquatic snails. The absence of unionid mussels (which require a fish host for glochidia larval development; Parmalee, 1967) and presence of only sphaerid clams suggest that the waters did not maintain a fish population. The terrestrial snails appear to have inhabited the basin after infilling with peat. The smaller vertebrates, such as beaver and duck, could have visited the waters at any time during lake infilling. The mastodont was deposited at approximately 11,160 B.P. The occurrence of algae, water milfoil, and cattails in the sediments indicate that some open water was present at the time of deposition. The unusual rise in such hardwood taxa as ash and hornbeam has also been noted in other regional pollen profiles (e.g., Bailey, 1972) from about the same time period (i.e., at approximately 11,500 B.P.) and regionally seems to predate a second rise in spruce that is followed by postglacial immigration of hardwood species (D.R. Whitehead, pers. comm.).

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## LITERATURE CITED

Bailey, R.E. 1972. Late- and postglacial environmental change in northwestern Indiana. Ph.D. Thesis, Indiana Univ., Bloomington, 72 pp.

Bleuer, N. and W.N. Melhorn. 1989. Glacial terrain models, north-central Indiana — the application of downhole logging to analysis of glacial vertical sequences. *In: Field Guidebook for the 23rd Annual Meeting of the North-Central Section of the Geological Society of America,* pp. 41-93, Univ. Notre Dame, 171 pp.

Cope, E.D. and J.L. Wortman. 1884. Post-Pliocene vertebrates of Indiana. *In:* J. Collett (Ed.), *14th Annual Report of the Indiana Department of Geology and Natural History, Second Part,* pp. 1-62, Burford Printing, Indianapolis, Indiana, 62 pp.

Elrod, N.M. and A.C. Benedict. 1892. Geology of Wabash County. *In:* S.S. Gorby (Ed.), *17th Annual Report of the Indiana Department of Geology and Natural Resources,* pp. 192-272, Burford Printing, Indianapolis, Indiana, 705 pp.

Graham, R.W., J.A. Holman, and P.W. Parmalee. 1983. Taphonomy and paleoecology of the Christensen bog mastodon bone bed, Hancock County, Indiana. Illinois State Mus. Rep. Invest. 38, 29 pp.

Gray, H.H. 1989. Quaternary geologic map of Indiana. Misc. Map 49, Indiana Geol. Survey, Bloomington.

Hay, O.P. 1912. The Pleistocene period and its vertebrata. *In:* E. Barrett (Ed.), *36th Annual Report of the Indiana Department of Geology and Natural Resources,* pp. 539-784, Burford Printing, Indianapolis, 873 pp.

Kurtén, B. and E. Anderson. 1980. Pleistocene mammals of North America. Columbia Univ. Press, New York, 443 pp.

Laws, R.M. 1966. Age criteria for the African elephant, *Loxodonta a. africana.* East African Wildl. J. 4: 1-37.

Mickelson, D.M., L. Clayton, D.S. Fullerton, and H.W. Borns, Jr. 1983. The Late Wisconsin glacial record of the Laurentide Ice sheet in the United States. *In:* S.C. Porter (Ed.), *Late Quaternary Environments of the United States, Vol. I, The Late Pleistocene,* pp. 3-37, Univ. Minnesota Press, Minneapolis, 407 pp.

Osborn, H.F. 1936. Proboscidea, a monograph of the diversity, evolution, migration, and extinction of the mastodons and elephants of the world, Vol. I. American Mus. Natur. Hist., New York, 802 pp.

Parmalee, P.W. 1967. The fresh-water mussels of Illinois. Pop. Sci. Ser. VIII, Illinois State Mus., 108 pp.

Richards, R.L. 1984. The Pleistocene vertebrate collection of the Indiana State Museum, with a list of the extinct and extralocal Pleistocene vertebrates of Indiana. Proc. Indiana Acad. Sci. 93: 483-504.

________, D.R. Whitehead, and D.R. Cochran. 1988. The Dollens mastodon (*Mammut americanum*) locality, Madison County, east central Indiana. Proc. Indiana Acad. Sci. 97: 571-581.

Saunders, J.J. 1977. Late Pleistocene vertebrates of the western Ozark highland, Missouri. Illinois State Mus. Rep. Invest. 33, 118 pp.

Schneider, A.F. and G.H. Johnson. 1967. Late Wisconsin glacial history of the area around Lake Maxinkuckee. Proc. Indiana Acad. Sci. 76: 328-334.

Skeels, M.A. 1962. The mastodons and mammoths of Michigan. Pap. Michigan Acad. Sci. Arts Lett. XLVII: 101-133.

Wayne, W.J. 1963. Pleistocene formations in Indiana. Indiana Dep. Conserv., Geol. Surv. Bull. 25, 85 pp.

________ and W.D. Thornbury. 1951. Glacial geology of Wabash County, Indiana. Indiana Dep. Conserv., Geol. Surv. Bull. 5, 39 pp.

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# GENETIC AND SIDESTREAM SMOKE EFFECTS ON DIFFERENCES OF MURINE BIRTH WEIGHT

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Abstract: An inherent problem with any study involving the effects of an environmental factor on phenotypic expression is the separation of genetic from environmental impact. In this study, interstrain crosses of BALB/c and C57BL mice were examined in an attempt to separate genetic differences of birth weight from those produced by sidestream smoke. Birth weight means of progeny produced by parental generations of BALB/c (1.59 g) and C57BL (1.23 g) mice are significantly different ($P < 0.01$). Two sample T-tests of parental, $F_1$, $F_2$, and backcross generations show significant strain and treatment effects on birth weight variability and support an additive model of birth weight inheritance with no appreciable dominance. Two-way analysis of variance suggests that the influence of the genetic character of pups and dams is greater than that of the sires. Two-way analysis of variance also indicates that there is no interaction between genetic and sidestream smoke effects. A minimum number of two genes appears to be associated with murine birth weight.

## INTRODUCTION

Numerous papers have discussed the effects of environmental factors on phenotypic expression. An environmental agent that has received attention in the past few years is sidestream smoke. Sidestream smoke is the smoke inhaled by nonsmokers by passive or involuntary smoking.

Recent research has shown that passive smoking may acutely aggravate angina pectoris (Aronow, 1978), increase the risk of fatal ischemic heart disease (Garland, *et al.,* 1985), induce small-airway dysfunction (Hulka, 1988; Tager, *et al.,* 1983; White and Froeb, 1980), enhance the effects of emphysema (Office of Smoking and Health, 1986), and increase the risk of lung cancer (Correa, *et al.,* 1983; Wigle, *et al.,* 1987). A reduction in the mean birth weight of infants of women passively-exposed to smoke has also been demonstrated (Campbell, *et al.,* 1988; Haddow, *et al.,* 1988; Martin and Bracken, 1986; Mochizuki, *et al.,* 1985).

In addition, a variety of animal studies have demonstrated the deleterious effects of sidestream smoke. These include reduced birth weight (Mays, 1986; Resnik and Marquard, 1980) and increased perinatal mortality (Essenberg, *et al.,* 1940; Mays, 1986; Mays, *et al.,* 1988).

An inherent problem with any study of the effects of an environmental factor on phenotypic expression is the separation of genetic impact from that of the environment (treatment). One of the major advantages of animal experimentation is that variables can be better controlled than they can in human studies. In this investigation, gene differences of birth weight of two inbred strains of mice were evaluated in an attempt to separate genetic from sidestream smoke (environmental) effects. Interstrain crosses between the two lines of mice were used to evaluate differences in birth weight. The following aspects of birth weight were assessed: the 1) degree of birth weight differences; the 2) influence of pup, dam, and sire genetic character; the 3) effect of sidestream smoke; the 4) type of genetic variance (e.g., additive or non-additive; dominance,

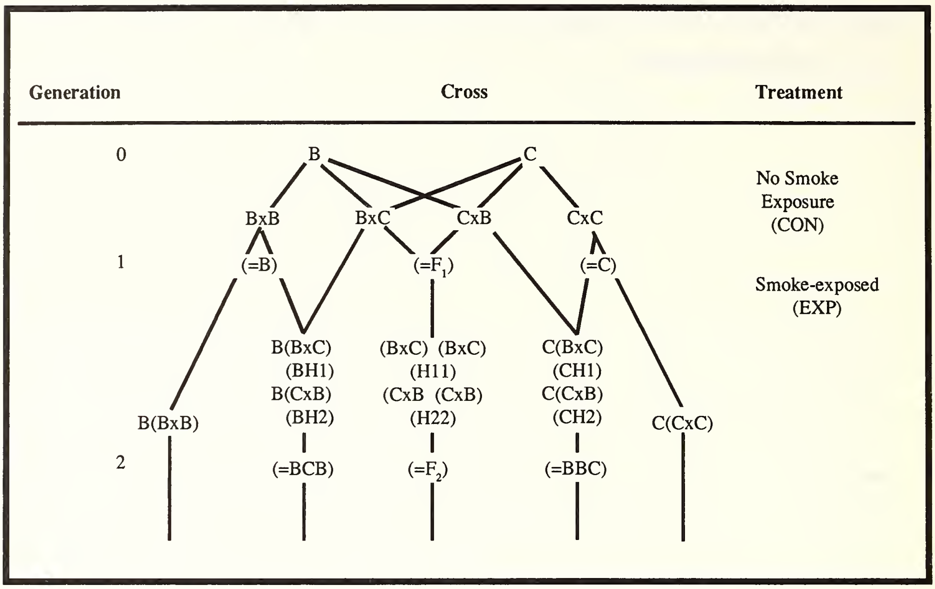

Figure 1. Schematic outline of genetic crosses performed between BALB/c (B) and C57BL (C) mice. Treatments for each generation are indicated. Parenthetical symbols are consistent with and identify the crosses as they are referred to in the analysis of results (e.g., BCB and BCC indicate backcrosses to the BALB/c and C57BL parents, respectively). The first letter of a cross represents the female.

incomplete dominance, or no dominance); and the 5) number of genes involved. Data were pooled by genetic character of pups, dams, and sires to illustrate strain (genetic) and treatment (environmental) effects.

## MATERIALS AND METHODS

Crosses of adult BALB/cAnNHsd and C57BL/6NHsd mice were performed according to the scheme of Hayes (1987) as outlined in Figure 1. Symbol designates are: B = BALB/c, C = C57BL, H1 = hybrid produced by a BxC cross, H2 = hybrid produced by a CxB cross, BCB = backcross to BALB/c parent, and BCC = backcross to C57BL parent. The parental cross equals the 0 generation. The first letter of a cross represents the strain of the female.

Control and experimental female mice were mated overnight with appropriate males. The day a copulation plug was found was designated as gestation day 1. Pregnant mice were maintained in separate cages under environmental conditions controlled with respect to room temperature (20-25° C), humidity (55-60%), and photoperiod (12 hr light, 12 hr dark). They were fed Lab Blox pellets (Wayne Feed Division, Continental Grain Co.) and water *ad libitum* between trials.

Experimental mice were placed in a plexiglass smoking chamber (25.5 cm x 30.5 cm x 21.0 cm) containing 6 airholes 6.5 mm in diameter on two opposite sides and exposed each day of gestation (21 days) to sidestream smoke from one filter-tip cigarette. The duration of each smoking session was 40 minutes. At the end of each

Table 1. Genetic model for birth weight. Control cumulative (cum) mean birth weights of progeny obtained from parental, F1, F2, and backcrosses using the inbred strains of BALB/c and C57BL mice.

| Cross | N[1] | Observed Birth Weight (g) (Mean ± SD) | Predicted Birth Weight (g) |
|---|---|---|---|
| BxB | 21 | 1.593 ± 0.11 | |
| CxC | 25 | 1.231 ± 0.18 [2] | |
| **P(cum)** | **46** | **1.412 ± 0.21** | |
| BxC | 19 | 1.500 ± 0.13 | |
| CxB | 24 | 1.380 ± 0.13 | |
| **F1(cum)** | **43** | **1.440 ± 0.14** | **1.412 ns[3]** |
| H11 | 26 | 1.346 ± 0.11 | |
| H22 | 10 | 1.294 ± 0.05 | |
| **F2(cum)** | **36** | **1.320 ± 0.10** | **1.412[*]** |
| BH1 | 15 | 1.480 ± 0.12 | |
| BH2 | 22 | 1.468 ± 0.13 | |
| H1B | 8 | 1.422 ± 0.11 | |
| H2B | 12 | 1.412 ± 0.20 | |
| **BCB(cum)** | **57** | **1.446 ± 0.15** | **1.513[*]** |
| CH1 | 22 | 1.281 ± 0.11 | |
| CH2 | 13 | 1.361 ± 0.04 | |
| H1C | 25 | 1.372 ± 0.13 | |
| H2C | 13 | 1.341 ± 0.08 | |
| **BCC(cum)** | **73** | **1.339 ± 0.12** | **1.336 ns[3]** |

[1] N = number of litters.

[2] The difference between BxB and CxC mean birth weights is significant ($P < 0.01$).

[3] ns = not significant.

[*] $P < 0.05$.

Table 2. Experimental cumulative (cum) mean birth weights of progeny obtained from parental, F1, F2, and backcrosses using the inbred strains of BALB/c and C57BL mice.

| Cross | N[1] | Observed Birth Weight (g) (Mean ± SD) | Predicted Birth Weight (g) |
|---|---|---|---|
| BxB | 38 | 1.526 ± 0.12 | |
| CxC | 35 | 1.219 ± 0.09[2] | |
| **P(cum)** | **73** | **1.373 ± 0.19** | |
| BxC | 23 | 1.491 ± 0.12 | |
| CxB | 23 | 1.279 ± 0.13 | |
| **F1(cum)** | **46** | **1.385 ± 0.16** | **1.373 ns[3]** |
| H11 | 74 | 1.371 ± 0.22 | |
| H22 | 12 | 1.138 ± 0.08 | |
| **F2(cum)** | **86** | **1.255 ± 0.22** | **1.373[*]** |
| BH1 | 10 | 1.463 ± 0.06 | |
| BH2 | 14 | 1.427 ± 0.20 | |
| H1B | 27 | 1.456 ± 0.19 | |
| H2B | 15 | 1.286 ± 0.14 | |
| **BCB(cum)** | **66** | **1.408 ± 0.18** | **1.456 ns[3]** |
| CH1 | 15 | 1.280 ± 0.19 | |
| CH2 | 8 | 1.252 ± 0.18 | |
| H1C | 8 | 1.263 ± 0.12 | |
| H2C | 14 | 1.249 ± 0.17 | |
| **BCC(cum)** | **45** | **1.261 ± 0.16** | **1.302 ns[3]** |

[1] Number of litters.

[2] The difference between BxB and CxC mean birth weights is significant ($P < 0.01$).

[3] ns = not significant.

[*] $P < 0.05$.

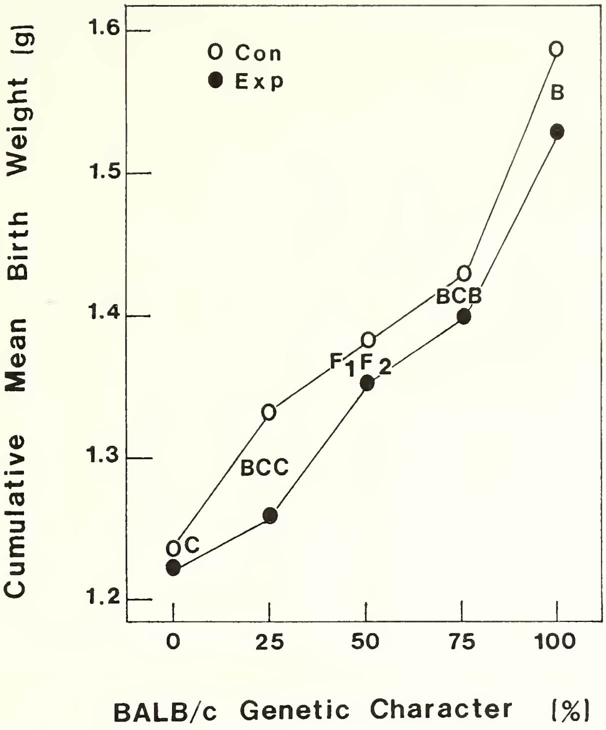

Figure 2. A comparison of cumulative mean birth weights of control and experimental progeny of crosses involving lines of BALB/c (B) and C57BL (C) mice. F1F2 represents the mean value of F1 and F2 progeny.

treatment period, dams were returned to their respective cages. Treatment was terminated at parturition. On postnatal day 1 (within 16 hr of birth), all litters were sexed and weighed. A total of four groups ($F_1$, $F_2$, BCB, BCC) were set up following the scheme in

$$E_F1 = (BW_B + BW_C)/2$$
$$E_F2 = (BW_B + BW_C)/2$$
$$E_BCB = (BW_C + BW_F1)/2$$
$$E_BCC = (BW_C + BW_F1)/2.$$

Statistical analyses were made using the Minitab program and VAX (Digital) mainframe computer. Two sample T-tests were used to compare observed and predicted cumulative mean birth weight values and to analyze differences between control mean birth weights (genetic effects), differences between experimental mean birth weights (treatment effects), and differences between control and experimental mean birth weights. Two-way analysis of variance (Rohlf and Sokal, 1969) was used to test for genetic (strain) effects, treatment (environmental effects), and interaction of strain and treatment as a function of pup, dam, and sire genetic character.

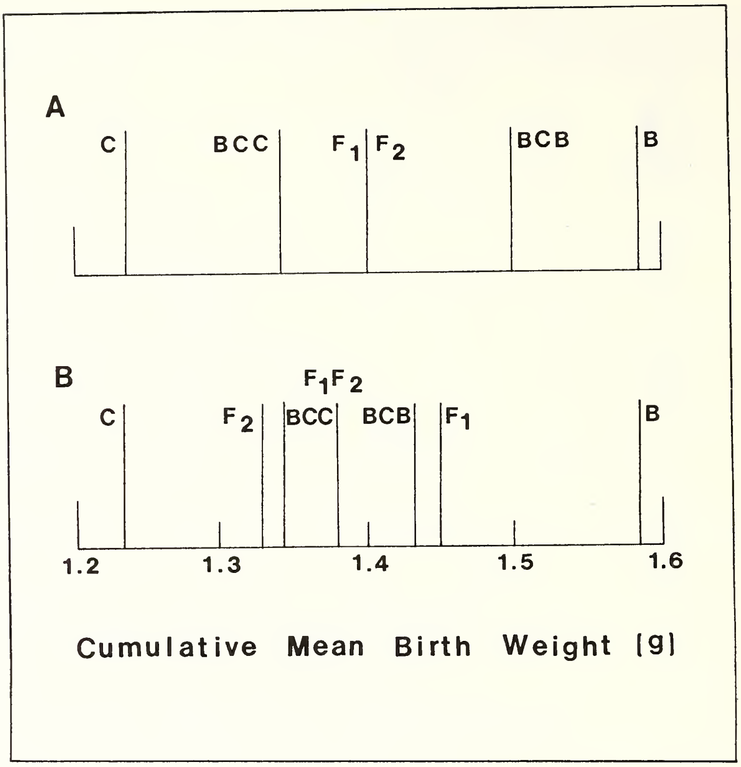

Figure 3. A comparison of observed cumulative mean birth weights among control progeny of crosses involving lines of BALB/c and C57BL mice with results predicted for an additive model with no dominance. Actual data for BALB/c (B), C57BL (C), and F1 were used to calculate expected values for F2 and the backcrosses to the BALB/c (BCB) and C57BL (BCC) lines. F1F2 represents the mean value of F1 and F2 progeny.

An estimate of the minimum number of genes contributing to character variation expressed by a quantitative trait (Angus, 1983; Lande, 1981) was used to define more precisely the genetic architecture underlying the differences in birth weight of the BALB/c and C57BL mouse populations.

## RESULTS

Comparisons of cumulative mean birth weights of parental, $F_1$, $F_2$, and backcross generations are shown for control (Table 1) and experimental mice (Table 2). The progeny mean birth weight of BALB/c controls (1.593 g) differs significantly ($P < 0.01$) from the mean birth weight of C57BL control progeny (1.231 g), and the mean birth weight of BALB/c experimental progeny (1.526 g) differs significantly ($P < 0.01$) from the mean birth weight of C57BL experimental progeny (1.219 g).

Our results suggest that the genetic effect on birth weight is additive (Figure 2). The data were tested to see if they fit an additive model with no dominance according to an inheritance model described by Henrich and Denlinger (1983). If inheritance of birth weight is additive with no dominance, the $F_1$ progeny should show a cumulative mean

Table 3. A comparison of mean birth weights (BW) of control and smoke-exposed mice as a function of pup genetic character.

| % BALB Genetic Char (Pups) | Con Cross | N[1] | BW | Group Pooled N | Group Pooled BW[2] | Exp Cross | N | BW | Group Pooled N | Group Pooled BW[2] |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | CxC | 25 | 1.23 | 25 | 1.23 | CxC | 35 | 1.22 | 35 | 1.22 |
| | | | | | (0.18) | | | | | (0.09) |
| 25 | CH1 | 22 | 1.28 | 73 | 1.34 | CH1 | 15 | 1.28 | 45 | 1.26 |
| | CH2 | 13 | 1.36 | | (0.12) | CH2 | 8 | 1.25 | | (0.16) |
| | H1C | 25 | 1.37 | | | H1C | 8 | 1.26 | | |
| | H2C | 13 | 1.34 | | | H2C | 14 | 1.25 | | |
| 50 | BxC | 19 | 1.50 | 36 | 1.38 | BxC | 23 | 1.49 | 132 | 1.32 |
| | CxB | 24 | 1.38 | | (0.12) | CxB | 23 | 1.28 | | (0.19) |
| | H11 | 26 | 1.35 | | | H11 | 74 | 1.37 | | |
| | H22 | 10 | 1.29 | | | H22 | 12 | 1.14 | | |
| 75 | BH1 | 15 | 1.48 | 57 | 1.45 | BH1 | 10 | 1.46 | 66 | 1.41 |
| | BH2 | 22 | 1.47 | | (0.15) | BH2 | 14 | 1.43 | | (0.18) |
| | H1B | 8 | 1.42 | | | H1B | 27 | 1.46 | | |
| | H2B | 12 | 1.41 | | | H2B | 15 | 1.29 | | |
| 100 | BxB | 21 | 1.59 | 21 | 1.59 | BxB | 38 | 1.53 | 38 | 1.53 |
| | | | | | (0.11) | | | | | (0.12) |

F-Interaction = (MS INTER)/(MS ERROR); 4df/140df
= 0.00424/0.00302
= 1.04 ns[3]

F-Strain = (MS STRAIN)/(MS ERROR); 4df/140df
= 0.48865/0.00302
= 161.805[**]

F-Treatment = (MS TREAT)/(MS ERROR); 1df/140df
= 0.07990/0.00302
= 26.457[**]

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[1] N = number of litters.

[2] Pooled mean birth weights (± SD) for the various genetic groupings.

[3] ns = not significant.

[**] $P < 0.01$.

Table 4. A comparison of mean birth weights (BW) of control and smoke-exposed mice as a function of dam genetic character. F- ratios are presented for two-way analysis of variance of observed (pooled) data.

| % BALB Genetic Char (Pups) | Con Cross | N[1] | BW | Group Pooled N | Group Pooled BW[2] | Exp Cross | N | BW | Group Pooled N | Group Pooled BW[2] |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | CxB | 24 | 1.38 | 84 | 1.31 | CxB | 23 | 1.28 | 81 | 1.26 |
| | CH1 | 22 | 1.28 | | (0.12) | CH1 | 15 | 1.28 | | (0.15) |
| | CH2 | 13 | 1.36 | | | CH2 | 8 | 1.25 | | |
| | CxC | 25 | 1.23 | | | CxC | 35 | 1.22 | | |
| 50 | H1B | 8 | 1.42 | 94 | 1.36 | H1B | 27 | 1.46 | 150 | 1.30 |
| | H2B | 12 | 1.41 | | (0.11) | H2B | 15 | 1.29 | | (0.15) |
| | H11 | 26 | 1.35 | | | H11 | 74 | 1.37 | | |
| | H22 | 10 | 1.29 | | | H22 | 12 | 1.14 | | |
| | H1C | 25 | 1.37 | | | H1C | 8 | 1.26 | | |
| | H2C | 13 | 1.34 | | | H2C | 14 | 1.25 | | |
| 100 | BxB | 21 | 1.59 | 77 | 1.51 | BxB | 38 | 1.53 | 85 | 1.48 |
| | BH1 | 15 | 1.48 | | (0.13) | BH1 | 10 | 1.46 | | (0.13) |
| | BH2 | 22 | 1.47 | | | BH2 | 14 | 1.43 | | |
| | BxC | 19 | 1.50 | | | BxC | 23 | 1.49 | | |

F-Interaction = (MS INTER)/(MS ERROR); 2df/84df
= 0.00098/0.00385
= 0.255 ns[3]

F-Strain = (MS STRAIN)/(MS ERROR); 2df/84df
= 0.4127/0.00385
= 107.057[**]

F-Treatment = (MS TREAT)/(MS ERROR); 1df/84df
= 0.04947/0.0038
= 12.849[**]

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[1] N = Number of litters.

[2] Pooled mean birth weights (± SD) for the various genetic groupings.

[3] ns = not significant.

[**] $P < 0.01$.

Table 5. A comparison of mean birth weights (BW) of control and smoke-exposed mice as a function of sire genetic character. F-ratios are presented for two way analysis of variance of the observed (pooled) data.

| % BALB Genetic Char (Pups) | Con Cross | N[1] | BW | Group Pooled N | Group Pooled BW[2] | Exp Cross | N | BW | Group Pooled N | Group Pooled BW[2] |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | BxC | 19 | 1.50 | 82 | 1.36 | BxC | 23 | 1.49 | 80 | 1.31 |
| | H1C | 25 | 1.37 | | (0.13) | H1C | 8 | 1.26 | | (0.13) |
| | H2C | 13 | 1.34 | | | H2C | 14 | 1.25 | | |
| | CxC | 25 | 1.23 | | | CxC | 35 | 1.22 | | |
| 50 | BH1 | 15 | 1.48 | 108 | 1.37 | BH1 | 10 | 1.46 | 133 | 1.32 |
| | BH2 | 22 | 1.47 | | (0.09) | BH2 | 14 | 1.43 | | (0.16) |
| | H11 | 26 | 1.35 | | | H11 | 74 | 1.37 | | |
| | H22 | 10 | 1.29 | | | H22 | 12 | 1.14 | | |
| | CH1 | 22 | 1.28 | | | CH1 | 15 | 1.28 | | |
| | CH2 | 13 | 1.36 | | | CH2 | 8 | 1.25 | | |
| 100 | BxB | 21 | 1.59 | 65 | 1.45 | BxB | 38 | 1.53 | 103 | 1.39 |
| | H1B | 8 | 1.42 | | (0.14) | H1B | 27 | 1.46 | | (0.15) |
| | H2B | 12 | 1.41 | | | H2B | 15 | 1.29 | | |
| | CxB | 24 | 1.38 | | | CxB | 23 | 1.28 | | |

F-Interaction = (MS INTER)/(MS ERROR); 2df/84df
= 0.00026/0.00913
= 0.0285 ns[3]

F-Strain = (MS STRAIN)/(MS ERROR); 2df/84df
= 0.12402/0.00913
= 13.584**

F-Treatment = (MS TREAT)/(MS ERROR); 1df/84df
= 0.04733/0.00918
= 5.184*

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[1] N = Number of litters.

[2] Pooled mean birth weights (± SD) for the various genetic groupings.

[3] ns = not significant.

* $P < 0.05$.

** $P < 0.01$.

Table 6. Comparison of the effects of genotype (controls) and environment (treatment) on birth weight (BW) as a function of pup genetic character determined by differences between controls (genetic effects) and differences between experimentals (treatment effects). The first letter of a cross represents the female.

| Genetic Charac (Pups) | Differences Between Control Mean Birth Weights (Genetic Effects) | Differences Between Experimental Mean Birth Weights (Treatment Effects) | Control vs Experimental Differences |
|---|---|---|---|
| | Cross/(BW) | Cross/(BW) | Cross/(BW) |
| 100% BALB/c | no diff | no diff | BxB $^{*}$<br>(1.59/1.53) |
| 75% BALB/c<br>25% C57 | no diff | BH1 vs H2B $^{**}$<br>(1.46) (1.29)<br>HIB vs H2B $^{**}$<br>(1.46) (1.29) | no diff |
| 50% BALB/c<br>50% C57 | BxC vs CxB $^{**}$<br>(1.50) (1.38)<br>H11 $^{**}$<br>(1.35)<br>H22 $^{**}$<br>(1.29)<br>CxB vs H22 $^{*}$<br>(1.38) (1.29) | BxC vs CxB $^{**}$<br>(1.49) (1.28)<br>H11 $^{**}$<br>(1.37)<br>H22 $^{**}$<br>(1.14)<br>CxB vs H11 $^{*}$<br>(1.28) (1.37)<br>H22 $^{**}$<br>(1.14)<br>H11 vs H22 $^{**}$<br>(1.37) (1.14) | H22 $^{**}$<br>(1.29/1.14)<br>CxB $^{*}$<br>(1.38/1.28) |
| 25% BALB/c<br>75% C57 | CH1 vs H1C $^{*}$<br>(1.28) (1.37)<br>CH2 $^{*}$<br>(1.36) | no diff | H1C $^{*}$<br>(1.37/1.26) |
| 100% C57 | no diff | no diff | no diff |

$^{*}$ $P < 0.05$.
$^{**}$ $P < 0.01$.

Table 7. Comparison of the effects of genotype (controls) and environment (treatment) on birth weight (BW) as a function of dam genetic character determined by differences between controls (genetic effects) and differences between experimentals (treatment effects). The first letter of a cross represents the female.

| Genetic Charac (Dams) | Differences Between Control Mean Birth Weights (Genetic Effects) | Differences Between Experimental Mean Birth Weights (Treatment Effects) | Control vs Experimental Differences |
|---|---|---|---|
| | Cross/(BW) | Cross/(BW) | Crosss/(BW) |
| 100% BALB/c | BxB vs BH1 * (1.59) (1.48) | BxB vs BH1 * (1.53) (1.46) | BxB * (1.59/1.53) |
| | BH2 * (1.47) | | |
| | BH1 ** (1.48) | | |
| | BxC * (1.50) | | |
| 50%BALB/c 50%C57 | H1B vs H22 * (1.42) (1.29) | H1B vs H2B ** (1.46) (1.29) | H1C * (1.37/1.26) |
| | H22 vs H1C * (1.29) (1.37) | H22 ** (1.14) | H22 * (1.29/1.14) |
| | | H1C ** (1.26) | |
| | | H2C ** (1.25) | |
| | | H2B vs H22 ** (1.29) (1.14) | |
| | | H11 vs H22 ** (1.37) (1.14) | |
| | | H1C ** (1.26) | |
| | | H22 vs H1C * (1.14) (1.26) | |
| 100% C57 | CxB vs CH1 ** (1.38) (1.28) | CxB vs CxC * (1.28) (1.22) | CxB * (1.38/1.28) |
| | CxC * (1.23) | | |
| | CH1 vs CH2 * (1.28) (1.36) | | |
| | CxC ** (1.23) | | |
| | CH2 vs CxC * (1.38) (1.23) | | |

* $P < 0.05$.

** $P < 0.01$.

Table 8. Comparison of the effects of genotype (controls) and environment (treatment) on birth weight (BW) as a function of sire genetic character determined by differences between controls (genetic effects) and differences between experimentals (treatment effects). The first letter of a cross represents the female.

| Genetic Charac (Sires) | Differences Between Control Mean Birth Weights (Genetic Effects) | Differences Between Experimental Mean Birth Weights (Treatment Effects) | Control vs Experimental Differences |
|---|---|---|---|
| | Cross/(BW) | Cross/(BW) | Cross/(BW) |
| 100% BALB/c | BxB vs H1B $^{**}$ | BxB vs H2B $^{**}$ | BxB $^{*}$ |
| | (1.59) (1.42) | (1.53) (1.29) | (1.59/1.53) |
| | H2B $^{*}$ | CxB $^{**}$ | CxB $^{*}$ |
| | (1.41) | (1.28) | (1.38/1.28) |
| | CxB $^{**}$ | H1B $^{*}$ | |
| | (1.38) | (1.46) | |
| 50%BALB/c | BH1 vs H11 $^{**}$ | BH1 vs H11 $^{**}$ | H22 $^{**}$ |
| 50%C57 | (1.48) (1.35) | (1.46) (1.37) | (1.29/1.14) |
| | H22 $^{**}$ | H22 $^{**}$ | |
| | (1.29) | (1.14) | |
| | CH1 $^{**}$ | CH1 $^{**}$ | |
| | (1.28) | (1.28) | |
| | CH2 $^{**}$ | CH2 $^{**}$ | |
| | (1.36) | (1.25) | |
| | H11 vs CH1 $^{*}$ | H11 vs H22 $^{**}$ | |
| | (1.35) (1.28) | (1.37) (1.14) | |
| | CH1 vs CH2 $^{*}$ | H22 vs CH1 $^{*}$ | |
| | (1.28) (1.36) | (1.14 (1.28) | |
| 100% C57 | BxC vs H1C $^{**}$ | BxC vs H1C $^{**}$ | H1C $^{*}$ |
| | (1.50) (1.37) | (1.49) (1.26) | (1.37/1.26) |
| | H2C $^{**}$ | H2C $^{**}$ | |
| | (1.34) | (1.25) | |
| | CxC $^{**}$ | CxC $^{**}$ | |
| | (1.23) | (1.23) | |

$^{*}$ $P < 0.05$.
$^{**}$ $P < 0.01$.

Table 9. Estimates (n ± SE) of the minimum number of genes contributing to the variation observed in progeny birth weights of BALB/c and C57BL lines revealed through crosses (made according to the scheme presented in Figure 1).

| Population | N | μ | σ |
|---|---|---|---|
| PC57 | 25 | 1.231 | 0.01368900 |
| BCC | 68 | 1.333 | 0.02220100 |
| F1 | 43 | 1.433 | 0.02073600 |
| F2 | 36 | 1.332 | 0.00913936 |
| BCB | 40 | 1.437 | 0.01354890 |
| PBALB | 21 | 1.593 | 0.11363500 |

$n_1 = 1.3969491 \pm 0.6504702$

$n_3 = 2.8311284 \pm 5.2160255$

$n_2 = 1.6358308 \pm 0.8448572$

$n_4 = 1.1502128 \pm 0.5668104$

N = Litter size.
μ = Cumulative mean birth weight.
σ = Variance.

birth weight intermediate between the two parental lines. The actual $F_1$ cumulative mean birth weight (1.440 g) does not vary significantly from the predicted value of 1.412 g. Furthermore, statistical analysis produced no significant differences between the predicted (1.336 g) and observed (1.339 g) birth weights for the BCC cross (Table 1). Thus, an additive model with no dominance for birth weight is assumed. The observed values and those predicted by an additive model with no dominance are shown in Figure 3. The same general pattern of birth weight inheritance occurs for the smoke-exposed progeny (Table 2).

Comparative mean birth weight data for control and experimental crosses were analyzed as a function of pup, dam, and sire genetic character. Five genetic categories (100% BALB/c, 75% BALB/c:25% C57BL, 50% BALB/c:50% C57BL, 25% BALB/c:75% C57BL, and 100% C57BL) were used to analyze the effect of pup genetic character on birth weight (Table 3). Three genetic categories (100% BALB/c, 50% BALB/c:50% C57BL, and 100% C57BL) were used to examine the effect of dam genetic character (Table 4) and sire genetic character (Table 5) on birth weight. Control and experimental pooled data for pup, dam, and sire genetic character produce an additive pattern. Although the analysis of both dam and sire genetic character indicates a slight bias toward the C57BL line, no significant differences were noted between any of the predicted and observed pooled values. Two-way analysis of variance shows the impact of genetic (strain) effects, treatment (environmental) effects, and interaction of strain and treatment as a function of pup (Table 3), dam (Table 4), and sire (Table 5) genetic character. Data from Tables 3 (pups), 4 (dams), and 5 (sires) were used to make a comparison of the effects of genetic character (strain) and environment (treatment) on birth weight. These effects were determined by differences between control mean birth weights (genetic effects), differences between experimental mean birth weights (treatment effects), and differences between control and experimental mean birth weights (genetic vs treatment effects) for pup (Table 6), dam (Table 7), and sire (Table 8) genetic character.

The minimum number of genes contributing to quantitative character variation between and within populations was estimated using the method proposed by Lande (1981). An estimate of two genes was obtained by comparing the phenotypic means ($\mu$) and the variances ($\sigma$) of the cumulative mean birth weights of parental ($n_1$), $F_1$ ($n_2$), $F_2$ ($n_3$), and backcross ($n_4$) generations. The results are presented in Table 9.

## DISCUSSION

A major difficulty associated with the analysis of the impact of environmental factors on a given phenotype is the separation of genetic effects. This investigation of the influence of sidestream smoke on the birth weight of mice is an attempt to make such a determination.

Employing modified Mendelian techniques, our control data from crosses between BALB/c and C57BL mice tend to fit an additive model of birth weight inheritance with no appreciable dominance. These results are in agreement with body weight inheritance for mammals in general (Roberts, 1981). Body weight tends to be highly heritable, where almost half of the natural variation may be genetic, and suggests that body weight is not a major component of fitness (Roberts, 1981). The results from smoke-exposed mice generally fit an additive model as well. However, for both control and experimental results, the fit to an additive model with no dominance is not perfect. The $F_2$ and BCB control crosses (Table 1) and the $F_2$ experimental cross (Table 2) differ from their respective predicted birth weights. In each of these cases, the observed cumulative birth weights are significantly lower than the birth weight predicted by the additive model. For example, the control $F_2$ cumulative mean birth weight is 1.320 g, which is significantly lower than the predicted weight of 1.412 g, but is close to the weight (1.380 g) of the lighter CxB parent. The fact that pooled mean birth weight data as a function of pup genetic character (Table 3), dam genetic character (Table 4), and sire genetic character (Table 5) demonstrate an additive pattern and that there are no significant differences between any of the predicted and observed pooled mean birth weights is supportive of an additive genetic model of birth weight inheritance with no dominance.

Two-way analysis of variance shows that there are significant strain (genetic) and treatment (environmental) effects on birth weight. F-ratios (Tables 3-5) suggest that genetic differences between pups and between dams have a larger effect on birth weight variability than do genetic differences between sires. The lack of significant interaction between genetic and sidestream smoke effects lends further support for an additive model of birth weight inheritance.

In some genetic categories, the genetic effects (differences between controls) and treatment effects (differences between experimentals) have an impact on birth weight variation. This is observed in the comparison of the crosses BxC and CxB in the

50%B:50%C category of pup genetic character (Table 6). In other cases, only the effects of genotype or treatment affect birth weight. A comparison of the control crosses CH1 (1.28 g) vs H1C (1.37 g) in the 25% B:75% C category of pup genetic character reveals significant genetic variation (Table 6). However, when exposed to sidestream smoke (experimental crosses), CH1 pup weight is unaffected (1.28 g vs 1.28 g), whereas H1C birth weight is reduced from 1.37 g to 1.26 g. Thus, the comparative birth weights upon smoke exposure (treatment effects) of 1.28 g (CH1) vs 1.26 g (H1C) are no longer significantly different. Similar examples are observed as a function of dam (Table 7) and sire (Table 8) genetic character.

There are four crosses that are significantly affected by sidestream smoke as shown by a comparison of differences between control and experimental mean birth weights. These crosses include BXB, CxB, H1C, and H22 with birth weight reductions of 0.07 g (4.4%), 0.10 g (7.3%), 0.11 g (8.0%), and 0.15 g (11.6%), respectively (Tables 6-8).

An important genetic factor controlling progeny birth weight is dam size. However, this does not completely explain the additive genetic effect noted. Dam size generally agrees with corresponding pup birth weight, but not absolutely. For instance, BALB/c dams are the largest (27.6 g) and have the largest pups (1.593 g), whereas C57BL dams are the smallest (21.4 g) and have the smallest pups (1.231 g). $F_1$ dams are intermediate in size (22.7 g) and have pups of intermediate size (1.440 g). But, although $F_1$ pup size falls in the predicted range based on an additive genetic model with no dominance, the dams are only slightly larger than C57BL dams. Therefore, additional genetic factors are indicated with regard to birth weight inheritance.

Following a mathematical model of Lande (1981), with modifications, four estimates were made of the minimum number of genes contributing to the variation in birth weight between and within BALB/c and C57BL lines. These estimates consistently indicate there are approximately two genes controlling birth weight of these two inbred murine lines. However, the estimate based on $F_2$ data was somewhat higher ($n_3 = 5.2$). The minimum number of genes estimated by this method can not exceed the number of chromosomal segments segregating independently in one generation (Lande, 1981). This is known at the **recombination index** (Darlington, 1937) and equals the haploid number of chromosomes plus the mean number of recombination events per gamete. In most higher plants and animals, the number of recombinations is limited to one or a few per chromosome per generation, so that the recombination index is usually on the order of a few times the haploid number of chromosomes. Since mice have a haploid number of 20, the actual number of genes associated with birth weight is probably greater than two with some linkage between them. The estimates reported here are in line with the average range of 5-10 genes reported for similar genotypic studies (Lande, 1981).

## SUMMARY

The purposes of this investigation were to determine the model that best fits murine birth weight inheritance, to separate genetic from environmental (sidestream smoke) influences on birth weight, and to identify the minimum number of genes associated with birth weight heritability. The results showed: that 1) the general pattern of birth weight inheritance is additive with no appreciable dominance, and that the same pattern occurred in smoke exposed mice; that 2) both genetic factors and sidestream smoke have a significant effect on birth weight variance; that 3) there is no significant interaction between genetic effects and sidestream smoke (treatment) effects; that 4) some crosses (genetic groups) involving C57BL and BALB/c strains are affected by sidestream smoke more than others; and that 5) the minimum number of genes controlling birth weight was found to be about two.

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## LITERATURE CITED

Angus, R.A. 1983. A program in BASIC for estimating the number of genes contributing to quantitative character variation. J. Hered. 74: 386.

Aronow, W.S. 1978. Effect of passive smoking on angina pectoris. New Engl. J. Med. 299: 21-24.

Campbell, M.J., J. Lewry, and M. Wailoo. 1988. Further evidence for the effect of passive smoking on neonates. Postgrad. Med. J. 64: 663-665.

Darlington, C.D. 1937. The biology of crossing over. Nature 140: 759-761.

Correa, P., L.W. Picle, E. Fontham, Y. Lin, and W. Haenszel. 1983. Passive smoking and lung cancer. Lancet 2: 595-597.

Essenberg, J.M., J.V. Schwind, and A.R. Patras. 1940. The effects of nicotine and cigarette smoke on pregnant female albino rats and their offspring. J. Lab. Clin. Med. 25: 708-717.

Garland, C., E. Barrett-Connor, L. Suarez, M.H. Criqui, and D.L. Wingard. 1985. Effects of passive smoking on ischemic heart disease mortality of nonsmokers: A prospective study. Amer. J. Epidemiol. 121: 645-649.

Haddow, J.E., G.J. Knight, G.E. Palomaki, and J.E. McCarthy. 1988. Second-trimester serum cotinine levels in nonsmokers in relation to birth weight. Amer. J. Obstet. Gynecol. 159: 481-484.

Hayes, J.L., D.J. Bandy, and H. Dingle. 1987. Genetic analysis of diapause differences between populations of the large milkweed bug. J. Hered. 78: 266-270.

Henrich, V.C. and D.L. Denlinger. 1983. Genetic differences in pupal diapause incidence between two selected strains of the flesh fly. J. Hered. 74: 371-374.

Hulka, B.S. 1988. The health consequences of environmental tobacco smoke. Environ. Technol. Let. 9: 531-538.

Lande, R. 1981. The minimum number of genes contributing to quantitative variation between and within populations. Genetics 99: 541-553.

Martin, T.R. and M.B. Bracken. 1986. Association of low birth weight with passive smoke exposure in pregnancy. Amer. J. Epidemiol. 124: 633-642.

Mays, C.E. 1986. Effects of sidestream smoke on pregnant mice and their offspring. Proc. Indiana Acad. Sci. 95: 529-535.

__________, M.W. Lingen, M.P. Sumida, and M.S. Willhite. 1988. Effects of sidestream smoke on reproduction and development of two inbred murine strains. Proc. Indiana Acad. Sci. 97: 537-545.

Mochizuki, M., T. Maruo, and K. Masuko. 1985. Mechanism of foetal growth retardation caused by smoking during pregnancy. Acta Physiol. Hung. 65: 295-304.

Office of Smoking and Health. 1986. The health consequences of involuntary smoking: A report of the Surgeon General. U.S. Department of Health and Human Services, Office of Smoking and Health, Rockville, Maryland, 359 pp.

Resnik, G. and G. Marquard. 1980. Effect of cigarette inhalation during pregnancy in Sprague-Dawley rats. J. Environ. Pathol. Toxicol. 45: 141-152.

Roberts, R.C. 1981. Genetic influences on growth and fertility. *In:* R.J. Berry (Ed.), *Biology of the House Mouse,* pp. 231- 254, Academic Press, New York, 715 pp.

Rohlf, F.J. and R.R. Sokal. 1969. Statistical tables. W.H. Freeman & Co., San Francisco, CA, 253 pp.

Tager, I.B., S.T. Weiss, A. Munoz, B. Rosner, and F.E. Speizer. 1983. Longitudinal study of the effects of maternal smoking on pulmonary function in children. New Engl. J. Med. 309: 699-703.

White, J.R. and H.F. Froeb. 1980. Small-airway dysfunction in nonsmokers chronically exposed to tobacco smoke. New Engl. J. Med. 302: 720-723.

Wigle, D.T., N.E. Collishaw, J. Kirkbride, and Y. Mao. 1987. Deaths in Canada from lung cancer due to involuntary smoking. Can. Med. Assoc. J. 136: 945-951.

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# SMALL MAMMALS OF THE PRAIRIE CREEK SITE, DAVIESS COUNTY, INDIANA

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ABSTRACT: Twenty-nine species of small mammals, including six extralimital species (*Condylura cristata,* the star-nosed mole; *Martes pennanti,* the fisher; *Tamiasciurus hudsonicus,* the red squirrel; *Clethrionomys gapperi,* the southern red-backed vole; *Microtus xanthognathus,* the yellow-cheeked vole; and *Lepus* cf. *L. americanus,* the snowshoe hare), were recovered from the Prairie Creek Site in Daviess County Indiana. Both Late Pleistocene (Zone D, 14,010 B.P.) and Holocene (Zone B, 2,880 - 4,140 B.P.) zones were distinguished along with an area of mixture (Zone C). The Late Pleistocene zone included several small mammals, whose presence provides support for the pollen and plant macrofossil interpretation that a spruce-dominated boreal forest surrounded Lake Prairie Creek and its associated marshes and wet meadows. The fauna includes a mixture of species (e.g., yellow-cheeked vole and star-nosed mole) that co-existed in the Late Pleistocene but have segregated distributions today. The Holocene zone included the remains of small mammals characteristic of an aquatic and marsh/meadow habitat with nearby deciduous woodlands, not unlike similar habitats in parts of Indiana today. Two Holocene extralimital species (the star-nosed mole and the fisher) appear not to have been as pressed for northern migration at the end of the Late Pleistocene as were some of the more boreal species.

## INTRODUCTION

The preservation of small mammal remains at the Prairie Creek Site, Daviess County, Indiana presents a unique opportunity to examine an aspect of lacustrine deposits not normally available, because of either low faunal diversity (Richards, Whitehead, and Cochran, 1988) or the lack of sampling for microfaunal remains. Most Indiana lacustrine deposits occur in "kettle" lakes in northern (Blatchley and Ashley, 1901) or in valleys tributary to former glacial sluiceways in southern Indiana (Gray, 1971). Recovery (or salvage) of vertebrate remains in the past usually involved large mammals such as the American mastodont, *Mammut americanum* (e.g., Hay, 1912, 1923; Kintner, 1930; Simpson, 1934; Sanford, 1935; Lyon, 1939). Only in more recent years have there been attempts to recover microfauna from lacustrine deposits, and the results have, until now, been sparse. The Kolarik mastodont locality, Starke County, Indiana produced remains of only the meadow vole (*Microtus pennsylvanicus*) and muskrat (*Ondatra zibethicus*) among the bones of fishes, frogs, mastodont, and caribou (*Rangifer tarandus*) (Richards and Ellis, in prep.). The Christensen Mastodont locality, Hancock County, Indiana yielded bones of the muskrat in Late Pleistocene levels and remains of the raccoon (*Procyon lotor*) and mink (*Mustela vison*) in Holocene sediments (Graham, Holman, and Parmalee, 1983). Extensive washing of the sediments at the Dollens mastodont locality, Madison County, Indiana, produced only remains of muskrat and an indet. mouse sp., though the remains occurred in marsh (peat) rather than lake sediments (Richards, Whitehead, and Cochran, 1988). Lacustrine and marsh deposits have been studied largely for their vegetational histories as provided by pollen and plant macrofossils (e.g., Englehardt, 1965; Gooding and Ogden, 1965; Whitehead, Jackson, Sheehan, and Leyden, 1982; Jackson, Whitehead, and Ellis, 1986; Richards, Whitehead, and Cochran, 1988). Because of this dearth of small mammal remains from lacustrine and marsh deposits, where vegetational histories are readily available, the 29 species of small mammals (including 6 extralimital species) recovered from the Prairie Creek Site are unique and important.

The caves of southern Indiana have produced extensive Quaternary microfaunas, including over 15 extralimital small mammals and reptiles (e.g., Richards, 1972, 1982, 1983, 1986). However, few of these cave deposits have been radiometrically dated, and none have associated pollen profiles as does the Prairie Creek Site.

In the summers of 1974 and 1975, the Department of Anthropology field school, Indiana University, and the Glenn A. Black Laboratory of Archaeology excavated biotic remains and archaeological materials from Quaternary-aged deposits of the Prairie Creek Site, Daviess County. Materials were recovered by trowling, with all matrix dry screened through 1/4" hardware mesh. Approximately 10% of the matrix was water screened through ca 1 mm hardware mesh (P.J. Munson, pers. comm.). The recovered vertebrate materials currently under study include the fishes (W.C. Dickinson), amphibians and reptiles (J.A. Holman and R.L. Richards, in prep.), birds (P.W. Parmalee, in prep.), small mammals (this paper), and large mammals ( P.J. Munson, in prep). Pollen and plant macrofossils have been reported upon (S.T. Jackson and D.R. Whitehead, unpublished ms.), and the excavation method and overview of the site is in preparation (P.S. Munson). The geology and sedimentology of the Prairie Creek lake basin has been treated by Fraser and Gray (in press). Their study reveals that from approximately 21,000 B.P. to 16,000 B.P., the West Fork of White River served as a glacial sliceway with outwash sediments damming the mouth of tributary Prairie Creek, resulting in the formation of a large lake. The lake accumulated up to 6 feet of organic mucks and biotic remains until about 13,000 B.P., when the valley train sediments in White River were eroded, the dam was breached, and the lake drained. Sediments and biotic remains were redeposited a mile or so downstream into the bed of Prairie Creek, the present fossil locality. A radiocarbon date of 14,010 ± 140 B.P. (DIC-234) on a spruce log indicates the time of faunal accumulation in the sample of sediments excavated (P.J. Munson, pers. comm.). Just before 10,000 B.P., perhaps as the result of dune formation at the mouth of Prairie Creek, a marsh formed in the basin, and by 4,200 B.P. (P.J. Munson, pers. comm.), a shallow stream meandered through the basin into the East Fork White River.

Zone D includes remains of Late Pleistocene vertebrates that inhabited the waters, shores, and region surrounding Lake Prairie Creek approximately 14,000 B.P., in addition to river margin vertebrates incorporated into the deposit during lake draining (P.J. Munson, pers. comm.). Zone B includes the Holocene (4,140- 2,880 B.P.) remains of vertebrates living in and about Prairie Creek and marshlands of the former lake as well as the surrounding region accumulated in the alluvial sediments of Prairie Creek. These included the food refuse of aboriginal meals that may have involved a wider diversity of exploited habitats than might be expected in the "natural" accumulations. Zone C consists of vertebrates primarily from Holocene sediments, with inclusions of Late Pleistocene remains scoured from the underlying Zone D deposits (P.J. Munson, per. comm.). Occasional Late Pleistocene elements (Zone D) have been redeposited in Holocene (Zone B) strata.

## CHECKLIST OF SMALL MAMMALS FROM THE PRAIRIE CREEK SITE, DAVIESS COUNTY, INDIANA

### The Late Pleistocene (Zone D)

| | |
|---|---|
| *Blarina brevicauda* | Northern short-tailed shrew |
| *Cryptotis parva* | Least shrew |
| *Sorex cinereus* | Masked shrew |
| *Condylura cristata*[#] | Star-nosed mole |
| *Scalopus aquaticus* | Eastern mole |
| *Martes pennanti*[*] | Fisher |
| *Mustela frenata* | Long-tailed weasel |
| *Mustela vison* | Mink |
| *Marmota monax* | Woodchuck |
| *Tamias striatus* | Eastern chipmunk |
| *Tamiasciurus hudsonicus*[#] | Red squirrel |
| *Peromyscus* sp. | Deer and white-footed mice |
| *Clethrionomys gapperi*[#] | Southern red-backed vole |
| *Microtus pennsylvanicus* | Meadow vole |
| *Microtus xanthognathus*[#] | Yellow-cheeked vole |
| *Ondatra zibethicus* | Muskrat |
| *Synaptomys* sp. | Bog lemmings |
| *Zapus hudsonius* | Meadow jumping mouse |
| *Sylvilagus* cf. *S. floridanus* | Eastern cottontail |
| Leporidae, sp. indet. | Cottontails and hares |

### The Late Pleistocene - Holocene Mixture (Zone C)

| | |
|---|---|
| *Blarina brevicauda* | Northern short-tailed shrew |
| *Sorex cinereus* | Masked shrew |
| *Condylura cristata*[#] | Star-nosed mole |
| *Procyon lotor* | Raccoon |
| *Martes pennanti*[*] | Fisher |
| *Mustela vison* | Mink |
| *Sciurus carolinensis* | Gray squirrel |
| *Sciurus* cf. *S. niger* | Fox squirrel |
| *Clethrionomys gapperi*[#] | Southern red-backed vole |
| *Microtus pennsylvanicus* | Meadow vole |
| *Microtus pinetorum* | Pine vole |
| *Ondatra zibethicus* | Muskrat |
| *Synaptomys* sp. | Bog Lemmings |
| *Lepus* cf. *L. americanus*[#] | Snowshoe hare |
| *Leporidae, sp. indet.* | Cottontails and hares |

### The Holocene (Zone B)

| | |
|---|---|
| *Didelphis virginiana* | Virginia opossum |
| *Blarina brevicauda* | Northern short-tailed shrew |
| *Condylura cristata*# | Star-nosed mole |
| *Scalopus aquaticus* | Eastern mole |
| *Urocyon cinereoargenteus* | Gray fox |
| *Procyon lotor* | Raccoon |
| *Martes pennanti** | Fisher |
| *Mustela vison* | Mink |
| *Mephitis mephitis* | Striped skunk |
| *Glaucomys* cf. *G. volans* | Southern flying squirrel |
| *Marmota monax* | Woodchuck |
| *Sciurus carolinensis* | Gray squirrel |
| *Sciurus niger* | Fox squirrel |
| *Peromyscus* sp. | Deer and white-footed mice |
| *Microtus pennsylvanicus* | Meadow vole |
| *Microtus* cf. *M. pinetorum* | Pine vole |
| Leporidae cf. *Sylvilagus* sp. | Cottontail |
| Leporidae, sp. indet. | Cottontails and hares |

# Extralimital.
* Extirpated in historic times.

## SYSTEMATIC PALEOZOOLOGY

The minimum number of individuals (MNI) and number of identified skeletal pieces (NISP) of small mammals for each zone are presented in Table 1. Species accounts follow the nomenclature and order of presentation of Banks, *et al.* (1987). Modern species distributions are from Hall (1981) and Mumford and Whitaker (1982) with habitat and species associations from the latter, unless otherwise noted. Measurements (mm) were made by ocular micrometer at 15X or by dial calipers. The following abbreviations are used: I, C, P, and M for the upper incisor, canine, premolar, and molar, respectively; i, c, p, and m for the lower teeth; $\bar{x}$ for the arithmetic mean; S.D. for the standard deviation; O.R. for the observed range of measurements; C.V. for the coefficient of variation; N for the number of specimens; L for left; R for right; prox. for proximal; dist. for distal; frag. for fragment; and B.P. for before present (A.D. 1950). Catalogue numbers (in parenthesis) are marked on the specimens. The remains are housed at the Glenn A. Black Laboratory of Archaeology, Indiana University, Bloomington.

### Class Mammalia: Mammals
### Order Marsupialia: Marsupials
### Family Didelphidae: Large American opossums
### *Didelphis virginiana* Kerr, 1792; Virginia opossum

**Material.** Zone B: R dentary, ant. portion (453/1); Rp2 (1237/4); thoracic vertebra (453/4); and L radius, prox. end (766/6).

| Taxon | Zone D | | Zone C | | Zone B | |
|---|---|---|---|---|---|---|
| | MNI[1] | NISP[2] | MNI | NISP | MNI | NISP |
| *Didelphis virginiana* | — | — | — | — | 1 | 4 |
| *Blarina brevicauda* | 2 | 10 | 1 | 1 | 2 | 2 |
| *Cryptotis parva* | 1 | 1 | — | — | — | — |
| *Sorex cinereus* | 2 | 2 | 1 | 1 | — | — |
| *Sorex* cf. *S. cinereus* | 1 | 3 | — | — | — | — |
| *Sorex* sp. indet. | — | 1 | — | — | — | — |
| *Condylura cristata*[#] | 3 | 5 | 1 | 1 | 1 | 1 |
| *Scalopus aquaticus* | 1 | 3 | — | — | 8 | 13 |
| *Urocyon cinereoargenteus* | — | — | — | — | 1 | 1 |
| *Procyon lotor* | — | — | 1 | 4 | 2 | 12 |
| Carnivore cf. *Procyon lotor* | — | — | — | — | — | 3 |
| *Martes pennanti*[*] | 3 | 5 | 1 | 2 | 1 | 3 |
| Carnivore cf. *Martes pennanti*[*] | — | 2 | — | 1 | 1 | 3 |
| *Mustela frenata* | 1 | 1 | — | — | — | — |
| *Mustela vison* | 2 | 5 | 1 | 4 | 4 | 10 |
| Carnivore cf. *Mustela vison* | — | 1 | — | — | — | 3 |
| *Mephitis mephitis* | — | — | — | — | 1 | 1 |
| Carnivore spp. indet. | — | 4 | — | 2 | — | 6 |
| *Glaucomys* cf. *G. volans* | — | — | — | — | 1 | 1 |
| *Marmota monax* | 1 | 1 | — | — | 1 | 1 |
| Rodent cf. *Marmota monax* | — | 1 | — | — | — | 1 |
| *Sciurus carolinensis* | — | — | 1 | 1 | 2 | 4 |
| *Sciurus* cf. *S. carolinensis* | — | — | — | — | 1 | 10 |
| *Sciurus niger* | — | — | — | — | 1 | 1 |
| *Sciurus* cf. *S. niger* | — | — | 1 | 1 | — | 1 |
| *Sciurus* sp. | — | — | — | 6 | — | 11 |
| *Tamias striatus* | 2 | 5 | — | — | — | — |

| Taxon | Zone D | | Zone C | | Zone B | |
|---|---|---|---|---|---|---|
| | MNI[1] | NISP[2] | MNI | NISP | MNI | NISP |
| Rodent cf. *Tamias striatus* | — | 1 | — | — | — | — |
| *Tamiasciurus hudsonicus*[#] | 1 | 3 | — | — | — | — |
| Sciuridae, spp. indet. | 1 | 1 | — | 2 | — | 2 |
| *Peromyscus* sp. | 2 | 3 | — | — | 2 | 3 |
| *Clethrionomys gapperi*[#] | 1 | 1 | 4 | 5 | — | — |
| *Microtus pennsylvanicus* | 1 | 1 | 1 | 1 | — | — |
| *Microtus* cf. *M. pennsylvanicus* | 3 | 7 | — | 2 | 1 | 2 |
| *Microtus pinetorum* | — | — | 1 | 1 | — | — |
| *Microtus* cf. *M. pinetorum* | — | — | — | — | 1 | 1 |
| *Microtus pinetorum/ochrogaster* | — | — | — | — | — | 1 |
| *Microtus xanthognathus*[#] | 2 | 3 | — | — | — | — |
| *Microtus* cf. *M. xanthognathus*[#] | — | 5 | — | — | — | — |
| *Microtus* sp. indet. | 2 | 7 | — | 4 | — | 4 |
| *Ondatra zibethicus* | 38 | 702 | 14 | 291 | 56 | 903 |
| *Synaptomys* sp. | 1 | 2 | 1 | 2 | — | — |
| Arvicolinae, spp. indet. | 2 | 16 | — | — | — | — |
| *Zapus hudsonius* | 1 | 1 | — | — | — | — |
| Mouse spp. indet. | — | 53 | — | 15 | — | 24 |
| Rodent sp. indet. | — | 1 | — | — | — | — |
| *Lepus* cf. *L. americanus*[#] | — | — | 1 | 1 | — | — |
| *Sylvilagus* cf. *S. floridanus* | 1 | 1 | — | — | — | — |
| *Sylvilagus* sp. | — | — | — | — | 1 | 1 |
| *Leporid* spp. indet. | — | 13 | — | 6 | — | 11 |
| Mammal spp. indet. | — | 162 | — | 43 | — | 106 |
| Totals | 75 | 1033 | 30 | 397 | 89 | 1150 |

[1] MNI = Minimum number of individuals.
[2] NISP = Number of identified skeletal pieces.
[#] Extralimital.
[*] Extirpated in historic times.

**Remarks.** The opossum is unknown from Late Pleistocene faunas north of Missouri, Kentucky, and Virginia (Kurtén and Anderson, 1980). It has apparently spread into more northern States in the past several thousand years (Guilday, 1958), being known from archaeological context in the early Holocene of east-central Illinois (Purdue and Styles, 1986). Opossum bones were recovered from only the Holocene zone at Prairie Creek. Although favoring wooded areas, the opossum also inhabits brushy and semi- open country and can spend considerable time along watercourses.

Table 1. Zonal distribution of the identified small mammal skeletal pieces at the Prairie Creek Site, Daviess County, Indiana.

### Order INSECTIVORA: Insectivores

### Family SORICIDAE: Shrews

### *Blarina brevicauda* (Say, 1823); Northern short-tailed shrew

**Material.** Zone D: L maxilla frag. (2460); RP3 (2693); L dentary frag. with i (2463); L dentary with ml (2686); L, R i (2460, 2693); Rm3 (2464); 2 L humeri (2335, 2460); and sacrum (2460). Zone C: RI (2597). Zone B: Frag. L dentary with m2 (2652); and L dentary portion, edentulous (2529).

**Remarks.** Dentaries were too fragmented for metric determination of subspecies (Graham and Semken, 1976; Jones, *et al.,* 1984). Two dentary fragments (2463 from Zone D and 2652 from Zone B) were measured for depth of ramus at m2, reading 2.31 mm and 2.02 mm, respectively. They appear no different in size than 15 modern Indiana *Blarina brevicauda kirtlandi* from the Indiana State University collection ( $\bar{x}$ = 2.28 mm; O.R. = 2.09 - 2.60 mm). The short-tailed shrew occurs in most Indiana habitats and is presently one of the most abundant mammals in the State.

### *Cryptotis parva* (Say, 1823); Least shrew

**Material.** Zone D: LP3 in maxilla frag. with 3 empty unicuspid alveoli (2335).

**Remarks.** The least shrew is found throughout Indiana in old fields, especially drier ones. Few have been recovered from woodlands.

### *Sorex cinereus* Kerr, 1792; Masked shrew

**Material.** Zone D: L dentary with ml (2460); and L dentary, edentulous (2463). Zone C: R dentary with p4-m3 (2459).

### *Sorex* cf. *S. cinereus*

**Material.** Zone D: L dentary, edentulous (2335); Lml (2335); and R dentary with p4-m2 (2335).

**Remarks.** Dentaries of *Sorex cinereus* and *S. longirostris* are very similar, and there is a general opinion that except for the slightly smaller size of the latter, the two are indistinguishable (Guilday, 1962; Guilday, Hamilton, and McCrady, 1966; Ray, 1967; Guilday, Hamilton, and McCrady, 1969; Guilday, Parmalee, and Hamilton, 1977; Guilday, Hamilton, Anderson, and Parmalee, 1978). *Sorex longirostris* has been reported only from Holocene localities in the Midwest (Parmalee, 1967; Richards, 1983) and the Pleistocene (Sangamonian) of Florida (Kurtén and Anderson, 1980). Richards (1983)

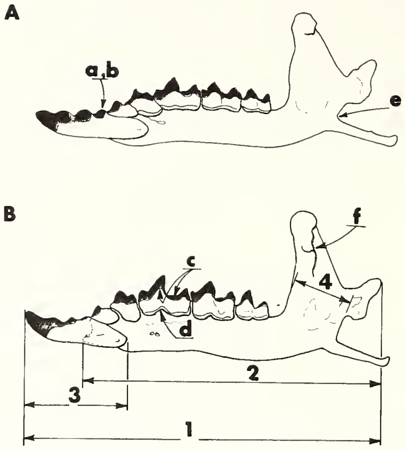

Figure 1. The left dentaries of *Sorex cinereus* and *S. longirostris* illustrating distinguishing measurements and morphological features. **A.** *Sorex cinereus*: a and b illustrate the size and pigmentation of the 3rd accessory tine of the incisor; and e refers to the shape of the lower portion of the sigmoid notch. **B.** *Sorex longirostris*: c points out the lower extent of the pigmentation on m1 and m2; d points out the development of the "notch" in the labial cingulum of m1 and m2; and f refers to the rugosity of sculpturing of the labial surface of the vertical ramus. One represents the total length of the mandible; 2, the total length of the dentary; 3, the length of the incisor; and 4, the width of the vertical ramus.

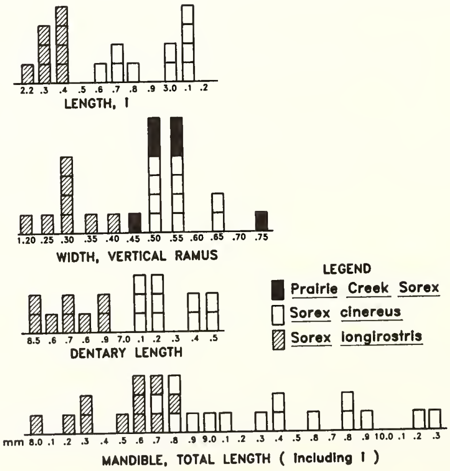

Figure 2. Four dimensions that have discriminated between *Sorex cinereus* and *S. longirostris* in a small sample. Figure 1 illustrates the actual measurements.

Table 2. Selected dentary/tooth measurements (mm) of *Sorex cinereus* from the Prairie Creek Site, Daviess County, Indiana.

| Unit | Element | Length p4-m3 | Length m1-m3 | Length m1 | Length m2 | Length m3 | Depth at m2 | Condyle width | Ht. Vert. ramus | Wth.Vert. ramus |
|---|---|---|---|---|---|---|---|---|---|---|
| **Zone D** | | | | | | | | | | |
| 2335 | R dentary | — | — | 1.19 | 1.10 | — | .89 | 1.47 | 3.06 | 1.48 |
| 2335 | L dentary | — | — | — | — | — | .89 | 1.40 | 3.08 | 1.55 |
| 2335 | Lm1 | — | — | 1.20 | — | — | — | — | — | — |
| 2460 | L dentary | — | — | 1.25 | — | — | .89 | 1.44 | — | 1.47 |
| 2463 | L dentary | — | — | 1.25 | — | — | .98 | — | 3.11 | 1.73 |
| **Zone C** | | | | | | | | | | |
| 2459 | R dentary | 3.70 | 3.10 | 1.22 | 1.09 | .93 | .88 | 1.47 | 2.96 | 1.49 |

suggested that the two species could be separated by the total length of the mandible (including incisor), total length of the dentary, length of the incisor, and width of the vertical ramus (Figures 1 and 2). Many of the other commonly presented measurements (e.g., toothrow lengths, tooth dimensions, and condyle width) segregate the two species only at the extremes or not at all (condyle width). All measurements are useful, however, in quantifying geographic variation in size, such as that displayed by *Sorex cinereus* (Guilday, Martin, and McCrady, 1964). The two can also be separated by a cluster of morphological traits (Figure 1) that includes the following: the greater size and heavier pigmentation of the 3rd accessory tine of the lower incisor in *S. cinereus* (Figure 1A, a, b; that of *S. longirostris* is smaller and scarcely pigmented, if at all); the lower extent of pigmentation especially on the m1 and m2 in *S. cinereus* (Figure 1B, c; the lower line of pigmentation on the labial surface of the protoconid is at approximately the same level as the labial ridge of the hypoconid in *S. cinereus* (it is above the level of the labial ridge in *S. longirostris*)); the weaker development of the small "notch" in the labial cingulum of m1 and m2 in *S. cinereus* (Figure 1B, d; the "notch" is stronger and more distinct in *S. longirostris*); the shape of the lower portion of the sigmoid notch (Figure 1A, e; the anteromost concavity tends to be in the lower portion of the notch in *S. cinereus* and is variable in position in *S. longirostris*); the lesser rugosity of sculpturing on the labial surface of the vertical ramus (including coronoid spicule and external temporal fossa) in *S. cinereus* (Figure 1B, f); and the tendency of the teeth of *S. cinereus* to be reddish, when pigmentation is preserved (more orangish in *S. longirostris*). These distinctions are based upon limited material with a narrow geographic range and should be pursued further.

The Prairie Creek materials are assigned to *S. cinereus* on a combination of metric and morphological characters. Measurements are presented in Table 2. The jaws were too fragmented for the measurements of toothrow and overall length commonly used to interpret geographic variation in size. However, the jaws did appear to be similar in size to the modern comparative material from Indiana.

*Sorex cinereus* ranks second only to *Blarina brevicauda* as the most abundant shrew in eastern Late Pleistocene cave deposits (Richards, 1983). Today, the masked shrew

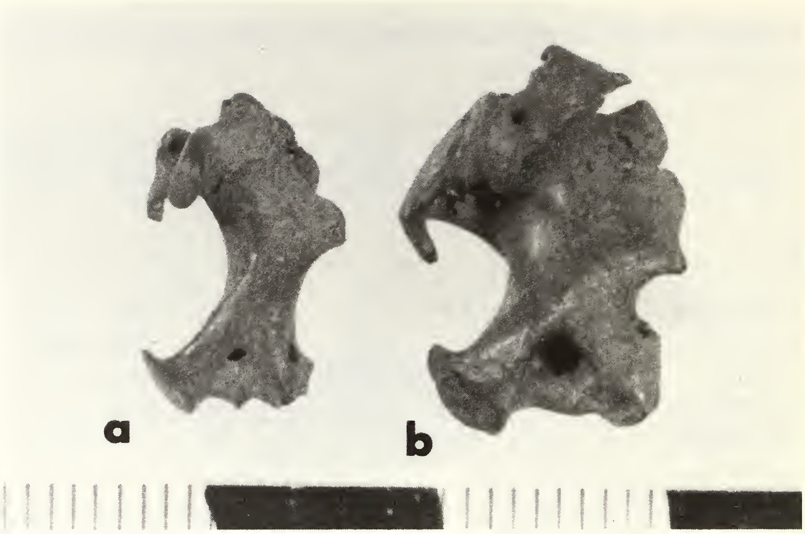

Figure 3. The left humeri (posterior view) of the moles found at the Prairie Creek Site, Daviess County, Indiana: **a**, *Condylura cristata* (Zone D: 2693); and **b**, *Scalopus aquaticus* (Zone B: L- 236/1). Note the more gracile form of *C. cristata*. Scale in millimeters.

inhabits moist environments with dense ground cover. Its common associates in northern Indiana, where it is common, are the meadow vole (*Microtus pennsylvanicus*), the northern short-tailed shrew (*Blarina brevicauda*), the white-footed mouse (*Peromyscus leucopus*), and the meadow jumping mouse (*Zapus hudsonius*), all of which were recovered from the Late Pleistocene zone at Prairie Creek. Neither the masked shrew nor the meadow jumping mouse were recovered from the Holocene zone.

### *Sorex* sp. indet.; Red-toothed shrews

**Material.** Zone D: L humerus (2464).

**Remarks.** The humerus compares favorably with that of *Sorex cinereus.*

### Family Talpidae: Moles

### *Condylura cristata* (Linnaeus, 1758); Star-nosed mole

**Material.** Zone D: L humerus (2693; Fig. 3); L humerus, prox. condyle (2464); L humerus (2335, pathological); ulna, prox. end (2335); and frag. tibiofibula (2335). Zone C: frag. ulna (2437). Zone B: frag. L humerus (222/4).

**Remarks.** The materials are shown in Fig. 3. This is the first report of the star-nosed mole as a fossil in Indiana. The star-nosed mole presently inhabits marshes, swampy areas, and stream banks in northeastern Indiana. The Prairie Creek Site is some 190 miles southwest of the nearest (Allen County) specimen-based record of the star-nosed mole. Interestingly, remains of this mole were recovered from both Late Pleistocene and Holocene zones at Prairie Creek. Extralimital star-nosed mole remains are also known from Crankshaft Cave, Missouri (Parmalee, Oesch, and Guilday, 1969). The hairy-tailed mole (*Parascalops breweri*) is likewise known as an extralimital fossil from a Late Pleistocene and Holocene context in Indiana (Parmalee, Munson, and Guilday, 1978; Richards, 1982). Perhaps moles in general, with their own "individualistic" environmental tolerances, were not as pressed for northern migration at the end of the Late Pleistocene as were some of the more boreal species.

### *Scalopus aquaticus* (Linnaeus, 1758); Eastern mole

**Material.** Zone D: Frag. L humerus (2703); ulna (1664/1); and tibiofibula, prox. end (2464). Zone B: Scapula (222/3); 7 L humeri (236/1 (Figure 3), 453/3, 859/1, 1061/1, 1387/1, 1387/2, 2529: bone #1); frag. L humerus (1238/7); 3 R humeri (453/2, 766/4, 2529: bone #2); and ulna (1238/3).

**Remarks.** The eastern mole is found today throughout Indiana in most terrestrial habitats. Although it is generally a temperate species, it did apparently co-exist with the more northern star-nosed mole (*Condylura cristata*) in all zones at Prairie Creek. Temperate climate and less water saturated soils in the Prairie Creek environment (as opposed to the marshes and meadows of the earlier Lake Prairie Creek) probably account for the relative abundance of the eastern mole in the Holocene zones.

### Order Carnivora: Carnivores

### Family Canidae: Wolves, coyotes, foxes

### *Urocyon cinereoargenteus* (Schreber, 1775); Gray fox

**Material.** Zone B: L radius, prox. shaft portion (766/5).

**Remarks.** Today, the gray fox is found throughout Indiana, although it is more common in the south, prefering brushy and wooded habitats.

### Family Procyonidae: Raccoons

### *Procyon lotor* (Linnaeus, 1758); Raccoon

**Material.** Zone C: L maxilla frag. with P4, M1, M2 (2197/1); RM1 (529/1); Lm1 (2330/1); and baculum (274/1). Zone B: L maxilla frag. with P4 (2199/1); R premaxilla with I2, I3 (453/9); cranial and palatal frags. (859/14); RC (222/2); RP4 (1239/1); RP4 (Unit IV W85-90, N10, B2); RM1 (1237/2); RM1 (Unit IV, W85-90, N10, B2); LM2 (1237/3); L dentary, post. portion (211/2); Rc (453/23); and Lm2 (1238/2).

### Carnivore cf. *Procyon lotor*

**Material.** Zone C: RP2 (2597). Zone B: C root (453/24); L dentary portion with c and p1, p2 alveoli (1082/1); and L ulna, prox. end (211/4).

**Remarks.** The raccoon is presently common throughout Indiana, frequenting wooded areas near water as well as more open country. It may originally have been confined to forested areas, including swamps. Interestingly, raccoon remains are not present in the Late Pleistocene zone at Prairie Creek, though they are well represented in the Holocene. The modern parapatric distribution of the temperate raccoon and the more boreal fisher (*Martes pennanti*) suggests that the absence of raccoon (and the presence of the fisher) in the Late Pleistocene zone is a reflection of the boreal climate and possibly of competition between the two species.

Table 3. Selected measurements (mm) of the remains of *Martes pennanti* (the fisher) from the Prairie Creek Site, Daviess County, Indiana.

| Element | Measurement | Zone | Catalog Number | L-R | Value | Sex |
|---|---|---|---|---|---|---|
| I3 | Anteroposterior length of crown | D | 513/1 | L | 4.57 | M |
| I3 | Transverse width of crown | D | 513/1 | L | 2.80 | M |
| C | Greatest anteroposterior diameter of root | D | 513/4 | R | 6.93 | M |
| C | Greatest transverse diameter of root | D | 513/4 | R | 6.07 | M |
| P2 | Length of crown | D | 794/1 | L | 5.72 | M |
| | | D | 513/1 | L | 6.17 | M |
| P2 | Width of crown | D | 794/1 | L | 2.87 | M |
| | | D | 513/1 | L | 2.87 | M |
| P3 | Length of crown | D | 794/1 | L | 7.51 | M |
| P3 | Width of crown | D | 794/1 | L | 3.54 | M |
| P4 | Length of crown | D | 794/1 | L | 12.14 | M |
| P4 | Anterior width of crown (across protocone, normal to labial surface) | D | 794/1 | L | 6.98 | M |
| | | D | 513/1 | L | 8.12 | M |
| P4 | Posterior width of crown (heel) | D | 794/1 | L | 4.14 | M |
| P2-P4 | Crown length | D | 794/1 | L | 26.09 | M |
| M1 | Greatest anteroposterior length of lingual lobe | C | 218/1 | L | 7.26 | ? |
| M1 | Greatest transverse width of crown | C | 218/1 | L | 10.21 | ? |
| c | Greatest anteroposterior diameter of root | C | 237/1 | L | ca. 7.18 | M |
| c | Greatest transverse diameter of root | C | 237/1 | L | 4.22 | M |
| Femur | Least anteroposterior diameter of shaft | D | 513/2 | L | 6.82 | M |
| Femur | Least transverse diameter of shaft | D | 513/2 | L | 7.5 | M |
| Humerus | Length from caput to medial condyle | D | 1497/1 | R | 81.05 | F |
| Humerus | Length from caput to medial sulcus of distal articulation | D | 1497/1 | R | 78.95 | F |
| Humerus | Anteroposterior depth of proximal end | D | 1497/1 | R | 15.08 | F |
| | | B | 211/3 | L | 18.26 | M |
| Humerus | Least transverse diameter of shaft | D | 1497/1 | R | 5.50 | F |
| Calcaneum | Greatest length | B | 229/1 | R | 27.15 | M |

### Family MUSTELIDAE: Mustelids

### *Martes pennanti* (Erxleben, 1777); Fisher

**Material.** Zone D: L maxilla with P2, P3, and P4, male (794/1); L maxilla + premaxilla with I3, P2, and P4, male (513/1); RC, male (513/4); R humerus, female (1497/1); and L femur, male (513/2). Zone C: LM1 (218/1); and Lc, male (237/1). Zone B: L dentary, condyle area, male (214/2); L humerus, prox. end, male (211/3); and R calcaneum, male (229/1).

### Carnivore cf. *Martes pennanti*

**Material.** Zone D: cervical vertebra (794/4); and thoracic vertebra, neural arch (794/5). Zone C: cervical vertebra (274/2). Zone B: Occipital with L condyle, male (230/2); R humerus, distal end, female (211/6); and ? radius shaft frag. (230/3).

**Remarks.** The fisher remains have previously been recorded and illustrated (Richards, 1993a). Measurements are presented in Table 3. The fisher does not presently inhabit Indiana, but there are several references to its historic occurrence (Mumford, 1969). Fisher remains have been recovered from two other Late Pleistocene localities (King Leo Cave, Harrison County and Megenity Peccary Cave, Crawford County; Richards, 1993a), from two archaeological sites (Ohio County (Kirkpatrick and Conaway, 1948) and Fort Ouiatenon, Tippecanoe County (Martin, 1986)), and from the Lake Michigan dunes (Rand and Rand, 1951). Tomak (1975) identified *Martes* remains from the original Prairie Creek investigation but did not conclude as to the species. (*Martes americana*, the marten, is known from several eastern Late Pleistocene localities (Kurtén and Anderson, 1980) but has not yet been found in Indiana). In the Late Pleistocene, the fisher was found as far south as Georgia, Arkansas, throughout the Appalachians, and west to Missouri (Kurtén and Anderson, 1980). The fisher inhabits extensive mixed hardwood forests (Burt and Grossenheider, 1952). It is among the few mammals that feed upon the porcupine (*Erethizon dorsatum*) (Kurtén and Anderson, 1980). Porcupine remains were not present in the Prairie Creek faunal sample.

### *Mustela frenata* Lichtenstein, 1831; Long-tailed weasel

**Material.** Zone D: LP3 (2672).

**Remarks.** The long-tailed weasel is found throughout Indiana today in most habitats and often near water.

### *Mustela vison* Schreber, 1777; Mink

**Material.** Zone D: 2 L humeri, dist. halves (200/2; 354/2); L radius, dist. end (2464); R radius, male (2463: bone #1); and L femur, female (354/1). Zone C: LM1 (217/2); L dentary with p4 and m1 (217/1); R dentary, post. portion, edentulous (374/1); and R humerus, lacking head (1465/1). Zone B: L dentary with p2, p3, m1, and m2 (214/1); L dentary with p3, m1, male (222/1); L dentary with m1 (453/5); L dentary with p3 and ml (453/6); frag. R dentary with p3 (453/7); L humerus, dist. ½, male (204/3); L ulna (766/2); R radius, distal 2/3 (859/5); L femur, prox. ½ (453/14); and R tibia, female (211/1).

### Carnivore cf. *Mustela vison*

**Material.** Zone D: Rc (2464). Zone B: L humerus, dist. 1/2 (204/4); frag. L dentary (453/8); and L astragalus (453/17).

**Remarks.** Remains of the mink were the most abundant of the carnivore bones at the Prairie Creek Site. This result is to be expected, as the mink occurs throughout Indiana today, frequenting the borders of lakes and marshes as well as the banks of rivers and creeks in both wooded and open environments. The mink is closely associated with the presence of muskrat (*Ondatra zibethicus*) today, just as it was throughout the Prairie Creek sequence.

### *Mephitis mephitis* (Schreber, 1776); Striped skunk

**Material.** Zone B: L ulna, prox. end (236/3).

**Remarks.** The striped skunk presently occurs throughout Indiana in a variety of habitats, including woods, brushy and weedy fields, and along streams and dry ravines.

## Order RODENTIA: Rodents

## Family SCIURIDAE: Squirrels

### *Glaucomys* cf. *G. volans* (Linnaeus, 1758); Southern flying squirrel

**Material.** Zone B: L tibia, lacking distal end (204/2).

**Remarks.** The tibia compares closely with that of *Glaucomys volans,* rather than the slightly larger (and boreal) *G. sabrinus.* The southern flying squirrel is found throughout Indiana in mature woods. Throughout its range, it occurs in deciduous or mixed deciduous-coniferous stands, while *G. sabrinus* inhabits the more northern conifer and mixed forests (Burt and Grossenheider, 1952). The presence of *G. volans* indicates more modern, Holocene vegetation during Zone B accumulation.

### *Marmota monax* (Linnaeus, 1758); Woodchuck

**Material.** Zone D: LI (1188/1). Zone B: R femur, prox. 1/2 (859/2).

### RODENT cf. *Marmota monax*

**Material.** Zone D: L dentary, angle area (496/1). Zone B: L humerus, dist. 1/2 (204/5).

**Remarks.** The woodchuck may originally have been an animal of the forest (Lyon, 1936). Today, however, the woodchuck is common throughout Indiana and is most abundant in more open areas, preferring brushy, uneven land, interspersed with cultivated fields.

### *Sciurus carolinensis* Gmelin, 1788; Gray squirrel

**Material.** Zone C: R humerus, prox. end (2597). Zone B: R scapula, glenoid cavity area (1086/2); L humerus shaft (453/22); and L humerus, distal end (859/7).

### *Sciurus* cf. *S. carolinensis*

**Material.** Zone B: R dentary with incisor (229/2); Rm3 (2538); L humerus, dist.

end (211/5); L femur, lacking dist. end (453/12); L femur, prox. end (453/21); L femur, prox. 1/2 (766/1); R femur, prox. end (2529); R tibia, dist. end (236/2); R tibia, lacking dist. end (453/10); and R calcaneum (453/11).

**Remarks.** The gray squirrel is found throughout Indiana, most abundantly in extensive, mature, mixed deciduous woodlands with a well developed understory. Its closest single associate is the fox squirrel (*Sciurus niger*). Both occurred only in the Holocene zone at Prairie Creek.

*Sciurus niger* Linnaeus, 1758; Fox squirrel

**Material.** Zone B: R femur (461/1).

*Sciurus* cf. *S. niger*

**Material.** Zone C: R dentary, edentulous (217/4). Zone B: R tibia, dist. end (204/1).

**Remarks.** The fox squirrel presently occurs throughout Indiana in less dense woodlands with less understory than its most common associate, the gray squirrel (*Sciurus carolinensis*). Both were recovered only from the Holocene zone at Prairie Creek.

*Sciurus* sp. indet.; Tree squirrel

**Material.** Zone C: LI (311/2); R ulna, prox. end (217/5); frag. R femur (217/6); L tibia, dist. end (2597); R tibia (1477/1); and R calcaneum (311/1). Zone B: 3 LI (222/5, 453/13, 1238/6); 2 RI (859/10, 1238/5); Li (859/11); Li frag. (VIIB, N2-4, W25-30+, Lev B5); R ischium (1238/4); R femur shaft (453/18); R tibia shaft (1237/1); and metatarsal (859/12).

*Tamias striatus* (Linnaeus, 1758); Eastern chipmunk

**Material.** Zone D: frag. L dentary with m2 (2460); Ri (2460); R humerus (2462); R tibia, prox. 2/3 (2335); and R tibia, prox. end (2461).

RODENT cf. *Tamias striatus*

**Material.** Zone D: Li, juvenile (1412/1).

**Remarks.** The chipmunk is common throughout Indiana, except in the southwestern part of the State and along the Ohio River, where it is of sporadic occurrence. It inhabits woodlands and woodland border habitats such as brushy fields and the borders of lakes. Suprisingly, it was recovered from only the Late Pleistocene zone at Prairie Creek.

*Tamiasciurus hudsonicus* (Erxleben, 1777); Red squirrel

**Material.** Zone D: R femur (1497/2); L tibia, lacking prox. end (849/2); and R tibia, dist. end (2703).

**Remarks.** The Prairie Creek femur is larger than several comparative Indiana specimens (total length from caput, 42.26 mm; total length from greater trochanter, 42.34 mm; and breadth of distal end, 7.25 mm). Today, the red squirrel is found in the northern two-thirds of Indiana, though there are a few sporadic records from the south-central and southwestern part of the State. It is generally found in pine and spruce forests, mixed hardwood forests, and swamps (Burt and Grossenheider, 1952). In Indiana, the red squirrel is known from hardwood forest (especially where conifers are present), isolated woodlots, and wooded stream borders and adjoining swamps. It is the most northern of the tree squirrels and was recovered only from the Late Pleistocene zone at Prairie Creek.

### Family Muridae: Rats, mice, voles
### Subfamily Sigmodontinae: New World rats and mice
### *Peromyscus* Gloger, 1841, sp. indet.; Deer and white-footed mice

**Material.** Zone D: L, R dentaries with i (2335); and L dentary with i (2464). Zone B: R dentary with i (766/8); R dentary, edentulous (2652); and Rm1 (2535).

**Remarks.** Relatively unworn m1's of eastern *Peromyscus* can sometimes be identified to species (Guilday, *et al.,* 1977; Ray, 1967). Unfortunately, the Prairie Creek dentaries lack molars. Today, both the white-footed (*Peromyscus leucopus*) and deer (*P. maniculatus*) mice occur throughout Indiana, occupying a variety of habitats from woodlands to dry, open fields.

### Subfamily Arvicolinae: Arvicoline rodents
### *Clethrionomys gapperi* (Vigors, 1830); Southern red-backed vole

**Material.** Zone D: L dentary, edentulous (2463). Zone C: LM3 (2654); Lm1 (2597); and 3 Lm1 (2654).

**Remarks.** The southern red-backed vole is not historically known from Indiana. The present material has previously been noted, as well as other Late Pleistocene material, from cave deposits in Lawrence, Harrison, and Jennings Counties, Indiana (Richards, 1986). The red-backed vole has been recovered extralimitally from over 20 Quaternary localities in Colorado, Nebraska, Kansas, Iowa, Missouri, Arkansas, Illinois, Kentucky, Tennessee, and Georgia (Richards, 1986). Some of the Illinois, Missouri, and Iowa sites are of Holocene age. *Clethrionomys* possesses rooted molars (as adults) and a characteristic occulusal enamel pattern (Semken, 1984). Today, the southern red-backed vole is most common in mixed conifer/deciduous forests, especially where the floor is littered with logs and stumps, though it can also be found in the brushy understory of forest edges (Semken, 1984). It was recovered with certainty only from the Late Pleistocene zone at Prairie Creek.

### *Microtus pennsylvanicus* (Ord, 1815); Meadow vole

**Material.** Zone D: LM3 (2460). Zone C: RM3 (2654).

### *Microtus* cf. *M. pennsylvanicus*

**Material.** Zone D: 2 L dentaries with m1 and m2 (2464, 2692); 2 R dentaries with m1 and m2 (2463, 2464); Lm1 (2463); and 2 Rm1 (2460, 2461). Zone C: Lm3 (2453); and Rm3 (2437). Zone B: R dentary with i, m1, and frag. m2 (859/13); and Lm2 (2652).

**Remarks.** The dentition of *Microtus pennsylvanicus* is generally inseparable from that of the rock vole, *M. chrotorrhinus,* except for the distinctive M3's (Semken, 1984).

The remaining molars with the "*pennsylvanicus*" pattern might include *M. chrotorrhinus* but, as suggested by the recovered M3's, are likely of *M. pennsylvanicus.* Fossil sites for *M. chrotorrhinus* have not yet been noted beyond the Appalachian area, where it has a sporadic occurrence today (Lundelius, *et al.,* 1983). Presently, the meadow vole is common to abundant in northern Indiana but relatively scarce in south-central and southwestern Indiana. It occurs in moist habitats such as low meadows, marshes, the grassy shores of lakes and streams, and grassy fields and has seldom been recovered from woodlands.

### *Microtus pinetorum* (Le Conte, 1830); Pine vole

**Material.** Zone C: Lm1 (2597).

### *Microtus* cf. *M. pinetorum*

**Material.** Zone B: Rm1 (2653).

### *Microtus pinetorum/M. ochrogaster* (Wagner, 1842); Prairie vole

**Material.** Zone B: RM2 (2428).

**Remarks.** *Microtus pinetorum* and *M. ochrogaster* have very similar dentitions. Johnson (1972) separated the two species using two measurements (neck width/posterior length ratio) of the m1, a method duplicated by Richards and Munson (1988) on Indiana material. The m1 of *M. pinetorum* has a relatively narrow, posteriorly directed 3rd buccal reentrant angle and a relatively posteriorly directed triangle 6 (Martin, 1987; Martin, pers. comm., Oct. 1988). The two Prairie Creek m1's are assigned to *M. pinetorum* by these modern Indiana neck width/posterior length ratios (2597: neck width, 0.21 mm, posterior length, 1.44 mm; 2653: neck width only, 0.23 mm) and by the criteria of Martin. The RM2 contains four elements, the condition in *Microtus pinetorum, M. ochrogaster,* and *M. chrotorrhinus,* though the last is of unlikely occurrence in the Holocene zone at Prairie Creek. Both the pine and the prairie vole occur throughout Indiana today, more commonly in the south. The pine vole occurs primarily in deciduous forest with soft soil and a leaf mold that allows easy burrowing, though it also occurs in brushy or grassy fields. Its most common associates are the northern short-tailed shrew (*Blarina brevicauda*) and the white-footed mouse (*Peromyscus leucopus*). The prairie vole prefers relatively dry grassy or weedy fields.

### *Microtus xanthognathus* (Leach, 1815); Yellow-cheeked vole

**Material.** Zone D: 2 LM1's, lacking ant. loops (2460, 2462); and LM3, lacking ant. loop (2460).

### *Microtus* cf. *M. xanthognathus*

**Material.** Zone D: Rm2, ant. frag. (2693); L ulna (2464); R innominate, acetabular area (2461); R femur (2461); and R femur, lacking distal end (2464).

**Remarks.** The teeth were identified by occlusal pattern, size, and the distribution of cement (Hallberg, Semken, and Davis, 1974). Postcranial material was referred by large size. These materials have been previously recorded (Richards, 1993b). Today, the yellow-cheeked vole occurs in northwestern Canada and Alaska. The nearest populations (northeast Manitoba) are about 2093 km (1300 miles) north of the Prairie Creek Site. It is known from one other Indiana Late Pleistocene locality (Megenity Peccary Cave, Crawford County; Richards, 1989) and over 20 others in Quebec, Pennsylvania, West Virginia, Virginia, Tennessee, Kentucky, Illinois, Missouri, Arkansas, Wisconsin, Iowa, and Wyoming (Hallberg, Semken, and Davis, 1974; Richards, 1993a). Today, the yellow-cheeked vole inhabits spruce forests and the bordering tundra (Burt and Grossenheider, 1952). Guilday (1971) related that it occurred in the open coniferous parklands at the forest fringe, rather than in the dense boreal forest. Yellow-cheeked vole remains were recovered only in the Late Pleistocene zone at Prairie Creek.

### *Ondatra zibethicus* (Linnaeus, 1766); Muskrat

**Material.** Zone D: 9 frontals; 3L, 3R temporals; 11L, 8R maxillae; 7L, 5R zygomatic processes of maxilla; 2L, 3R premaxillae; 4 palates; 17 cranial frags.; 6L, 5RI; 4 I frags.; 13L, 6RMI; 3L, 5RM2; 21L, 29R dentaries; 1L, 1R dentary tips; 2 articular processes of L dentaries; 19L, 24Ri; 21L, 21Rm1; 13L, 23Rm2; 7L, 4Rm3; 5 atlases; 2 cervical, 2 thoracic, 12 lumbar, 54 caudal vertebrae; 2 sacrabrae; 7 vertebrae frags.; 14 vertebrae centra epiphyses; 1 clavicle; 8 molar frags.; 1 rib; 2L, 4R scapulae; 18L, 16R humeri; L humerus, prox. end; L humerus, dist. end; 3L, 10R ulnae; 1L, 2R radii; 17L, 25R innominates; L ischium; 1L, 3R ilia; 30L, 37R femora; R femur, prox. end; 2 femur heads; 4 femur head epiphyses; distal femur epiphysis; 28L, 36R tibiofibulae; L tibiofibula, shaft frag. and distal epiphysis; L tibia, shaft frag. and distal end; R tibiofibula, distal end; R tibia, prox. epiphysis; 5L, 8R calcanea; 1L, 2R astragali; 18 metatarsals and fragments; 3 metapodials; and 4 proximal, 2 distal phalanges. Zone C: 4 frontals; 1L, 3R temporals; 2R maxillae; maxilla frag.; 2L, 1R zygomatic processes of maxilla; 4 cranial frags; 1 palate; 1L, 3RI; 4 I frags.; 7L, 4RM1; 2L, 2RM2; 2L, 2RM3; 11L, 9R dentaries; L dentary tip; 2L, 4R dentary frags.; R condyle frag.; 13L, 14Ri; 11L, 14Rm1; 8L, 7Rm2; 1L, 3Rm3; 2 i frags; 7 molar frags.; 4 lumbar, 13 caudal vertebrae; sacrum; 3 vertebrae centra epiphyses; 1 rib; R scapula; 4L, 5R humeri; 2 humeri head epiphyses; 12L, 12R femora; 1 femur head epiphysis; 3 femora distal epiphyses; 3L, 1R ulnae; 1L, 1R radii; 12L, 6R innominates; R innominate, acetabular area; 10L, 11R tibiofibulae; L tibia, distal end; tibiofibula, prox. epiphysis; R calcaneum; L astragalus; 20 metatarsals; and 6 phalanges. Zone B: 12L, 10R maxillae; maxilla frag.; 2L, 3R zygomatic processes of maxillae; 4 palates; palate frag.; 16 frontals; 2L temporals; 2L premaxillae; 4 cranial frags.; 5L, 6RI; 7 I frags.; 23L, 20RM1; 9L, 17RM2; 1L, 3RM3; 28L, 34R dentaries; 3L, 1R dentary frags.; 27L, 23Ri; 29L, 43Rm1; 17L, 18Rm2; 7L, 7Rm3; i frag.; 20 molar frags.; atlas; 2 cervical, 3 thoracic, 12 lumbar, 56 caudal vertebrae; 2 vertebrae frags.; 2 sacrabrae; 10 vertebrae centra epiphyses; clavicle; rib; 2R scapulae; 21L, 16R humeri; 3 humeri head epiphyses; 13L, 5R ulnae; ulna, dist. end; ulna shaft frag.; 6L, 4R radii; 2 R radii, distal ends; 23L, 24R innominates; R ischium frag.; 56L, 42R femora; femur head epiphysis; 4 femora distal epiphyses; 40L, 36R tibiofibulae; L tibiofibula frag.; tibia frag.; 8 tibiae proximal epiphyses; tibia, distal epiphysis; 4L, 6R calcanea; 3L, 3R astragali; 60 metatarsals, 1 frag.; and 18 phalanges.

**Remarks.** The muskrat was the most abundant mammal in all zones at Prairie Creek. Muskrat m1's from interglacial deposits and modern southern regions display significantly lower length/width ratios than those from glacial strata and modern northern re-

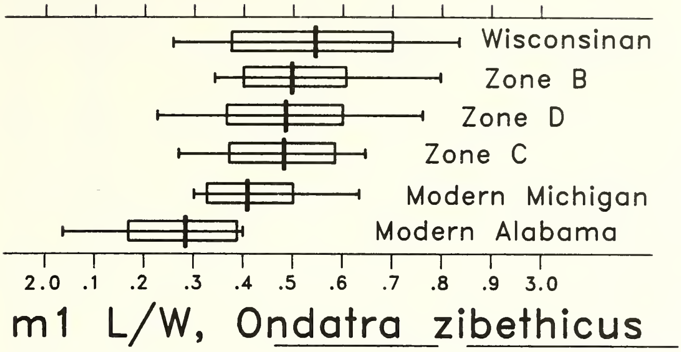

Figure 4. Length/width ratios for the first lower molar of *Ondatra zibethicus*. Zones B-D refer to the Prairie Creek Site. The arithmetic mean (vertical bar), one standard deviation (box), and the observed range (horizontal lines) are illustrated. Michigan, Alabama, and Wisconsinan-aged specimen data are from Nelson and Semken (1970).

gions (Semken, 1966; Nelson and Semken, 1970). Analysis of 103 m1's from Prairie Creek[1] shows high length/width ratios for all three zones, higher than a modern Michigan ratio, and nearest that of Wisconsinan-aged specimens from the Nelson-Semken study (Figure 4). Ratios of the Prairie Creek Late Pleistocene (Zone D, $\bar{x}$ = 2.48 mm) and Holocene (Zone B, $\bar{x}$ = 2.50 mm) m1's are quite similar (Table 4), and individual ratios overlap so greatly that there is little stratigraphic distinction on a bivariant plot. Although the differences are not statistically significant, it is interesting that the Holocene ratio is slightly more "northern" than that of the Late Pleistocene at Prairie Creek. Only two long bones displayed a tendency for completion of epiphyseal union (2 L femora have minor points of fusion between the diaphyses and loose epiphyses; L-513 from Zone D and L-1465 from Zone C). None of the other major limb bones display initial union of more than one end of the bone (e.g., there was no union of: humerus, prox. end; radius, dist. end; femur, dist. end; or tibiofibula, prox. end). Many of the muskrat teeth, however, display the heavy wear of old adults. This suggests that few muskrats reach full growth, even as adults, and adds a growth-related bias to postcranial measurement comparisons. It also masks temporal and geographic size variation in postcranial skeletal remains. Munyer (1964) also found a lack of epiphyseal union of postcranial elements in otherwise osteologicaly mature modern Illinois muskrats.

Measurements of the Prairie Creek muskrat materials are presented in Table 4. None of the mean ( $\bar{x}$ ) values between Prairie Creek Zones B and D and modern samples of select measurements displayed any differences that were statistically significant. An age

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[1] M1's were measured at their "girth" to reduce the variability produced by different degrees of wear. The girth is measured from the enamel convexity ("bow") at the anterior margin of the tooth to the posterior enamel margin of the tooth in a plane parallel to the occlusal wear surface (pers. comm., H.A. Semken, Jr., 25 May 1988).

Table 4. Selected measurements (mm) and ratios for *Ondatra zibethicus*.

| Element | Measurement | Zone | $\bar{x}$ [1] | O.R.[2] | S.D.[3] | C.V.[4] | N[5] |
|---|---|---|---|---|---|---|---|
| ml | Length/width ratio | Mod[6] | 2.43 | 2.35 - 2.60 | .092 | 3.79 | 7 |
| | | B | 2.50 | 2.34 - 2.80 | .104 | 4.17 | 47 |
| | | C | 2.48 | 2.27 - 2.65 | .098 | 3.97 | 21 |
| | | D | 2.48 | 2.23 - 2.77 | .117 | 4.72 | 35 |
| ml | First labial cement tract height | Mod | 5.19 | 1.53 - 7.04 | 2.391 | 46.10 | 7 |
| | | B | 5.57 | 0.00 - 9.80 | 2.864 | 51.41 | 65 |
| | | C | 6.18 | 1.70 - 9.90 | 2.398 | 38.83 | 23 |
| | | D | 5.22 | 0.10 - 9.50 | 2.674 | 51.21 | 40 |
| Dentary | Least depth from coronoid notch to base of horizontal ramus | Mod | 14.58 | 14.0 - 15.5 | 0.71 | 4.88 | 6 |
| | | B | 14.35 | 13.4 - 14.9 | 0.62 | 4.34 | 6 |
| | | C | 14.24 | 12.8 - 15.4 | 1.06 | 7.44 | 5 |
| | | D | 14.76 | 13.1 - 16.5 | 1.13 | 7.68 | 9 |
| Dentary | Depth from angle at junction of vertical and horizontal ramus to base of dentary | Mod | 11.33 | 10.7 - 11.9 | 0.45 | 3.97 | 8 |
| | | B | 11.44 | 10.1 - 12.6 | 0.69 | 6.04 | 19 |
| | | C | 11.51 | 10.6 - 12.6 | 0.81 | 7.08 | 8 |
| | | D | 11.48 | 10.5 - 12.4 | 0.57 | 4.92 | 18 |
| Dentary | Angular "notch" to anterior edge of ml alveolus | Mod | 25.91 | 25.6- 26.4 | 0.32 | 1.23 | 7 |
| | | B | 26.97 | 25.2 - 28.6 | 1.02 | 3.77 | 15 |
| | | C | 25.72 | 24.5 - 27.5 | 1.19 | 4.62 | 6 |
| | | D | 26.79 | 23.5 - 28.7 | 1.26 | 4.70 | 17 |
| Dentary | Angular "notch" to tip of dentary | Mod | 39.57 | 37.5 - 41.2 | 1.35 | 3.40 | 7 |
| | | B | 40.10 | 39.6 - 40.5 | — | — | 2 |
| | | C | 37.0 | 35.6 - 39.1 | 1.71 | 4.63 | 4 |
| | | D | 38.53 | 34.2 - 40.7 | 1.94 | 5.04 | 12 |
| Scapula | Least antero-posterior diameter of "neck" | Mod | 5.37 | 5.0 - 5.7 | 0.26 | 4.77 | 7 |
| | | B | — | —— | — | — | — |
| | | C | — | —— | — | — | — |
| | | D | 4.84 | 4.5 - 5.2 | 0.33 | 6.79 | 5 |
| Scapula | Transverse width across glenoid cavity | Mod | 4.5 | 4.3 - 4.8 | 0.22 | 4.80 | 7 |
| | | B | 4.6 | 4.6 | — | — | 1 |
| | | C | — | —— | — | — | — |
| | | D | 4.64 | 4.6 - 4.8 | 0.09 | 1.93 | 5 |
| Humerus | Total length | Mod | 36.04 | 34.0 - 38.7 | 1.79 | 4.97 | 7 |
| | | B | 39.15 | 37.1 - 42.5 | 2.09 | 5.33 | 6 |
| | | C | 38.67 | 36.7 - 40.7 | 2.00 | 5.17 | 3 |
| | | D | 35.89 | 34.2 - 38.5 | 1.63 | 4.54 | 7 |

| Element | Measurement | Zone | $\bar{x}$[1] | O.R.[2] | S.D.[3] | C.V.[4] | N[5] |
|---|---|---|---|---|---|---|---|
| Humerus | Greatest width of shaft across deltoid "flange" | Mod[6] | 9.97 | 8.7 - 10.9 | 0.76 | 7.65 | 7 |
| | | B | 9.51 | 7.9 - 10.6 | 1.13 | 11.93 | 8 |
| | | C | 10.13 | 10.1 - 10.2 | 0.05 | 0.49 | 4 |
| | | D | 9.51 | 7.7 - 11.1 | 0.94 | 9.87 | 10 |
| Humerus | Least oblique width of shaft ("flange" area) | Mod | 4.16 | 3.7-4.5 | 0.28 | 6.64 | 7 |
| | | B | 3.94 | 3.4-4.9 | 0.34 | 8.75 | 22 |
| | | C | 3.93 | 3.7-4.0 | 0.13 | 3.19 | 7 |
| | | D | 3.86 | 2.8-4.6 | 0.50 | 13.01 | 26 |
| Humerus | Transverse width of distal end from medial process to lateral articular margin | Mod | 11.43 | 10.9 - 11.7 | 0.27 | 2.35 | 7 |
| | | B | 11.49 | 9.6 - 13.1 | 0.88 | 7.62 | 15 |
| | | C | 11.24 | 10.8 - 11.5 | 0.29 | 2.56 | 5 |
| | | D | 11.31 | 10.1 - 12.2 | 0.60 | 5.35 | 15 |
| Ulna | Total length | Mod | 50.13 | 48.5 - 53.4 | 1.98 | 3.95 | 7 |
| | | B | — | ——— | — | — | — |
| | | C | 49.8 | 49.8 | — | — | 1 |
| | | D | 52.0 | 52.0 | — | — | 1 |
| Ulna | Greatest antero-posterior width through semilunar notch | Mod | 5.3 | 4.8 - 6.0 | 0.39 | 7.39 | 7 |
| | | B | 5.5 | 4.9 - 6.3 | 0.46 | 8.29 | 6 |
| | | C | 5.73 | 5.1 - 6.3 | 0.60 | 10.52 | 3 |
| | | D | 5.58 | 4.7 - 6.3 | 0.59 | 10.53 | 8 |
| Ulna | Greatest antero-posterior diameter of shaft (ca. 10 mm below semilunar notch) | Mod | 4.77 | 4.2 - 5.2 | 0.40 | 8.45 | 7 |
| | | B | 5.05 | 4.8 - 5.3 | — | — | 2 |
| | | C | 4.75 | 4.7 - 4.8 | — | — | 2 |
| | | D | 4.68 | 4.2 - 5.1 | 0.41 | 8.73 | 5 |
| Ulna | Least transverse diameter of shaft below semilunar notch | Mod | 2.64 | 2.5 - 2.9 | 0.15 | 5.73 | 7 |
| | | B | 2.59 | 2.3 - 2.8 | 0.20 | 7.54 | 7 |
| | | C | 2.75 | 2.7 - 2.8 | — | — | 2 |
| | | D | 2.56 | 2.3 - 2.9 | 0.26 | 10.19 | 5 |
| Radius | Total length | Mod | 38.06 | 36.8 - 41.4 | 1.69 | 4.43 | 7 |
| | | B | 41.7 | 41.7 | — | — | 1 |
| | | C | — | ——— | — | — | |
| | | D | 36.3 | 34.5 - 38.5 | 2.03 | 5.59 | 3 |
| Radius | Greatest diameter, proximal end | Mod | 4.81 | 4.6 - 5.3 | 0.24 | 5.01 | 7 |
| | | B | 5.1 | 4.8 - 5.4 | — | — | 2 |
| | | C | — | ——— | — | — | — |
| | | D | 4.78 | 4.5 - 5.1 | 0.26 | 5.42 | 5 |

| Element | Measurement | Zone | $\bar{x}$[1] | O.R.[2] | S.D.[3] | C.V.[4] | N[5] |
|---|---|---|---|---|---|---|---|
| Radius | Least diameter, proximal end | Mod[6] | 2.9 | 2.6 - 3.1 | 0.18 | 6.30 | 7 |
| | | B | 3.17 | 3.0 - 3.4 | 0.21 | 6.57 | 3 |
| | | C | — | —— | — | — | — |
| | | D | 2.88 | 2.6 - 3.4 | 0.31 | 10.81 | 5 |
| Radius | Greatest diameter, distal end | Mod | 5.34 | 5.1 - 5.7 | 0.21 | 4.02 | 7 |
| | | B | 5.18 | 4.6 - 5.7 | 0.41 | 7.89 | 5 |
| | | C | 5.2 | 5.2 | — | — | 1 |
| | | D | 4.8 | 4.4 - 5.5 | 0.61 | 12.67 | 3 |
| Radius | Least diameter, distal end | Mod | 3.81 | 3.7 - 4.0 | 0.11 | 2.81 | 7 |
| | | B | 3.68 | 3.2 - 3.9 | 0.32 | 8.70 | 4 |
| | | C | 4.1 | 4.1 | — | — | 1 |
| | | D | 3.4 | 3.0 - 3.8 | 0.40 | 11.76 | 3 |
| Innominate | Least vertical width, "neck" of ilium | Mod | 5.5 | 5.1 - 6.2 | 0.47 | 8.61 | 6 |
| | | B | 5.35 | 4.4 - 6.5 | 0.57 | 10.66 | 31 |
| | | C | 5.24 | 3.8 - 6.2 | 0.69 | 13.21 | 13 |
| | | D | 5.32 | 3.5 - 6.2 | 0.51 | 9.63 | 39 |
| Innominate | Least vertical width, "neck" of ischium | Mod | 7.37 | 7.0 - 7.6 | 0.21 | 2.80 | 6 |
| | | B | 7.01 | 5.9 - 8.0 | 0.61 | 8.70 | 17 |
| | | C | 6.50 | 5.2 - 7.4 | 0.85 | 13.11 | 8 |
| | | D | 7.18 | 6.6 - 7.9 | 0.40 | 5.58 | 14 |
| Innominate | Anteroposterior diameter of acetabulum (align with groove below postero-superior facet) | Mod | 8.1 | 7.6 - 8.6 | 0.41 | 5.06 | 6 |
| | | B | 7.98 | 7.5 - 8.5 | 0.38 | 4.77 | 8 |
| | | C | 7.95 | 7.5 - 8.6 | 0.47 | 5.86 | 4 |
| | | D | 8.1 | 7.6 - 9.0 | 0.45 | 5.55 | 10 |
| Femur | Total length, from greater trochanter | Mod | 44.76 | 42.6 - 47.5 | 1.91 | 4.27 | 7 |
| | | B | 44.65 | 28.3 - 49.4 | 5.26 | 11.79 | 14 |
| | | C | 47.03 | 43.1 - 50.3 | 3.13 | 6.66 | 4 |
| | | D | 45.56 | 28.9 - 49.7 | 4.29 | 9.41 | 19 |
| Femur | Total length, from head | Mod | 43.29 | 40.8 - 46.1 | 1.90 | 4.40 | 7 |
| | | B | 43.23 | 26.8 - 48.5 | 6.15 | 14.22 | 10 |
| | | C | 45.87 | 41.6 - 49.6 | 4.03 | 8.78 | 3 |
| | | D | 44.9 | 42.7 - 48.6 | 1.56 | 3.48 | 13 |
| Femur | Head, greatest diameter | Mod | 7.07 | 6.8 - 7.4 | 0.26 | 3.63 | 7 |
| | | B | 7.26 | 6.4 - 7.7 | 0.40 | 5.53 | 19 |
| | | C | 7.4 | 6.7 - 8.0 | 0.66 | 8.86 | 3 |
| | | D | 7.16 | 6.3 - 7.9 | 0.37 | 5.19 | 23 |

| Element | Measurement | Zone | $\bar{x}$ [1] | O.R.[2] | S.D.[3] | C.V.[4] | N[5] |
|---|---|---|---|---|---|---|---|
| Femur | Transverse width of shaft across "flange" | Mod[6] | 10.53 | 8.9 - 12.2 | 1.26 | 11.98 | 7 |
| | | B | 9.66 | 6.3 - 12.6 | 1.30 | 13.42 | 44 |
| | | C | 10.16 | 8.4 - 11.6 | 0.89 | 8.80 | 9 |
| | | D | 10.34 | 6.4 - 12.5 | 1.29 | 12.44 | 43 |
| Femur | Least anteroposterior width of shaft ("flange" area) | Mod | 5.24 | 4.6 - 5.7 | 0.36 | 6.87 | 7 |
| | | B | 4.81 | 3.7 - 6.0 | 0.42 | 8.66 | 65 |
| | | C | 4.83 | 4.2 - 5.5 | 0.41 | 8.49 | 20 |
| | | D | 5.03 | 3.8 - 5.8 | 0.40 | 7.98 | 58 |
| Femur | Greatest transverse width, distal end (oblique) | Mod | 10.6 | 9.5 - 11.8 | 0.86 | 8.13 | 7 |
| | | B | 10.31 | 8.4 - 11.4 | 0.98 | 9.52 | 13 |
| | | C | 10.98 | 9.6 - 11.9 | 0.98 | 8.90 | 4 |
| | | D | 10.84 | 8.5 - 12.5 | 1.00 | 9.24 | 22 |
| Femur | Width from tips of greater to lesser trochanters | Mod | 16.81 | 15.9 - 17.2 | 0.44 | 2.63 | 7 |
| | | B | 16.97 | 15.8 - 18.7 | 0.83 | 4.88 | 16 |
| | | C | 17.15 | 16.8 - 17.5 | 0.40 | 2.36 | 4 |
| | | D | 16.78 | 14.1 - 18.5 | 0.95 | 5.69 | 26 |
| Tibiofibula | Total length | Mod | 63.94 | 60.5 - 65.7 | 2.07 | 3.24 | 5 |
| | | B | 72.2 | 72.2 | — | — | 1 |
| | | C | 64.5 | 62.2 - 67.5 | 2.72 | 4.21 | 3 |
| | | D | 66.07 | 61.0 - 69.1 | 2.95 | 4.47 | 6 |
| Tibiofibula | Greatest transverse width, proximal end | Mod | 10.87 | 9.9 - 11.6 | 0.67 | 6.12 | 6 |
| | | B | 10.37 | 10.0 - 10.7 | 0.35 | 3.39 | 3 |
| | | C | 11.17 | 10.7 - 11.8 | 0.57 | 5.09 | 3 |
| | | D | 11.39 | 10.1 - 12.6 | 1.04 | 9.17 | 8 |
| Tibiofibula | Greatest transverse width of shaft at tibiofibula junction | Mod | 4.55 | 3.5 - 5.2 | 0.59 | 13.02 | 6 |
| | | B | 4.21 | 3.1 - 5.5 | 0.47 | 11.08 | 49 |
| | | C | 4.42 | 3.7 - 5.1 | 0.40 | 9.10 | 17 |
| | | D | 4.33 | 3.4 - 5.3 | 0.36 | 8.26 | 53 |
| Tibiofibula | Greatest anteroposterior width of distal end | Mod | 6.5 | 6.3 - 6.8 | 0.23 | 3.61 | 5 |
| | | B | 6.4 | 5.0 - 7.3 | 0.55 | 8.56 | 16 |
| | | C | 6.5 | 6.0 - 6.8 | 0.32 | 4.87 | 5 |
| | | D | 6.5 | 5.6 - 7.0 | 0.37 | 5.63 | 22 |
| Tibiofibula | Greatest transverse width, distal end | Mod | 11.26 | 10.7 - 11.7 | 0.44 | 3.90 | 5 |
| | | B | 10.85 | 8.1 - 11.8 | 0.97 | 8.90 | 13 |
| | | C | 11.37 | 10.2 - 12.2 | 0.66 | 5.83 | 6 |
| | | D | 11.07 | 10.0 - 12.1 | 0.58 | 5.22 | 23 |

[1] $\bar{x}$ = Arithmetic mean.

[2] O.R. = Observed range of measurements.

[3] S.D. = Standard deviation.

[4] C.V. = Coefficient of variation.

[5] N = Number of specimens.

[6] Mod = Modern skeltons, south-central Indiana caves (Richards'collection).

profile was constucted for each Prairie Creek zone by measuring the height of the first labial dentine tract (and thus amount of unworn tooth), a measurement previously used in taxonomic studies (Figure 5; Semken, 1966; Nelson and Semken, 1970). This profile indicated a generally similar age distribution for muskrats in all Prairie Creek zones. In an attempt to assess the non age-related size of postcranial elements from the three zones at Prairie Creek, histograms of measurements of an abundant element ("flange" width, femur) were matched to ten age classes (one for each mm of tooth wear) for empirical comparison (Figure 5). By tooth wear, Zone D displays a slightly older average muskrat age (i.e., lower values for the median (6.5 mm) and mean ( $\bar{x}$ = 5.22 mm) of m1 tract height) than in Zone B (7.0 mm for the median and 5.57 mm for the mean). Zone D also has a correspondingly larger femur "flange" width (for Zone D, the median was 10.5 mm and the mean was 10.34 mm; for Zone B, the median was 9.5 mm and the mean was 9.66 mm). This suggests that the postcranial measurement summaries (Table 4) do incur some age class (and thus size) bias between the various zones.

Three postcranial elements displayed pathology (Figure 6). The proximal 1/2 of a L femur (L-354 from Zone D; Figure 6b) reveals an apparently fractured and healed (with anteroposterior thickening) shaft. A second L femur (L-236 from Zone B; Figure 6c) suggests disease. It displays a smooth-edged, circular pit (approximately 5.3 mm in diameter and 3.1 mm deep) surrounded by degenerating bone on the anterior face of the proximal end. There is some remodeling of the muscle scars and a general roughening of the bone surface on the proximal 1/2 of the shaft. A R tibiofibula (L-236 from Zone B; Figure 6a) displays a remodeled puncture, piercing anteroposteriorily through the distal diaphysis/epiphysis plate interface. The adjacent distal fibula end has been remodeled to a swollen mass of bone.

Today, the muskrat is found throughout Indiana along streams and around lakes and ponds, but it is especially abundant in marshes and other waters that have abundant emergent vegetation. Its most common associates are the mink, raccoon, opossum, beaver, meadow vole, and star-nosed mole, and in drier situations around the marshes, the northern short-tailed shrew, masked shrew, and meadow jumping mouse (*Zapus hudsonius*).

### *Synaptomys* Baird, 1858 sp. indet.; Bog lemming

**Material.** Zone D: I frag. (2460); and R dentary, edentulous (2335). Zone C: LM1 (2654); and LM1 or M2, posterior 3 triangles (2654).

**Remarks.** Remains of *Synaptomys cooperi,* the southern bog lemming, and/or those of *S. borealis,* the northern bog lemming, could be represented in the Late Pleistocene zone. Fossils of the two are effectively distinguished only by lower molars (Semken, 1984), none of which were recovered at Prairie Creek. The southern bog lemming is presently found in grassy fields and occasionally woodlands throughout much of Indiana. The northern bog lemming is a Canadian species of wet alpine and subalpine meadows, muskeg, heaths, and sedges (Burt and Grossenheider, 1952). It has been recovered extralimitally at one Indiana Late Pleistocene locality (Megenity Peccary Cave, Crawford County; Richards, 1993b) and more than 21 others in Pennsylvania, Maryland, West Virginia, Virginia, Tennessee, Arkansas, Missouri, Wisconsin, Iowa, Wyoming, and Mon-

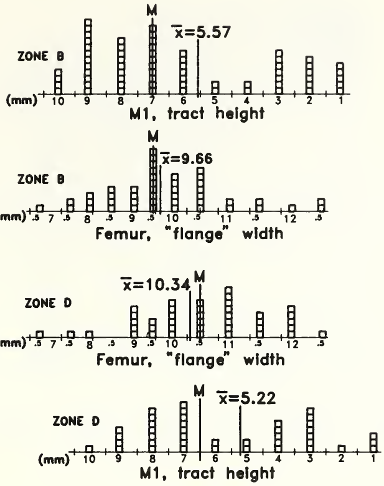

Figure 5. Age distribution (m1 tract height) correlated with femur "flange" width in *Ondatra zibethicus* from Zones B and D at the Prairie Creek Site. x̄ is the arithmetic mean, and M is the median. Each box represents one measurement. Calibrated in millimeters.

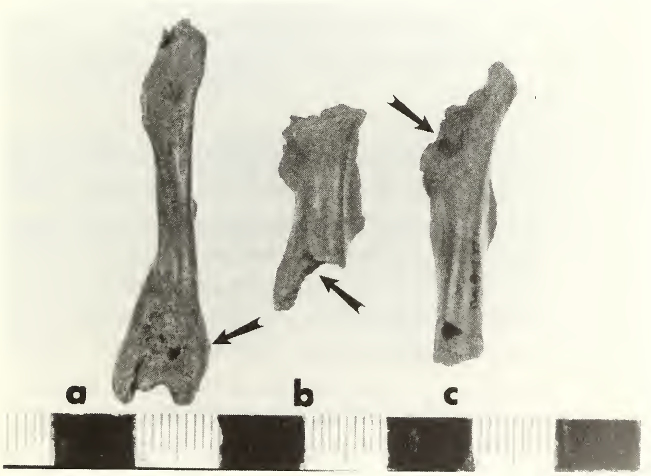

Figure 6. Muskrat (*Ondatra zibethicus*) pathology as evident at the Prairie Creek Site in Daviess County, Indiana: **a**, the right tibiofibula displaying a remodeled puncture of the distal end (Zone B: L-236); **b**, the proximal $^1/_2$, left femur, showing a fractured shaft along with the remodeled thickening of the shaft (Zone D: L-354); and **c**, the left femur displaying a smooth-edged, circular pit and bone resorption suggestive of disease (Zone B: L-236). Smallest scale in millimeters.

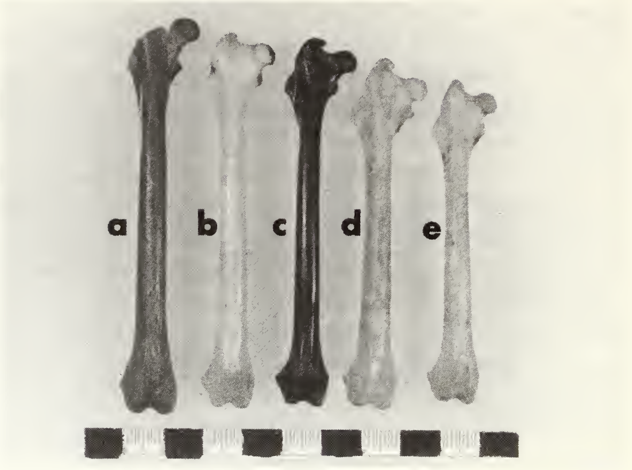

Figure 7. The right femora of *Lepus americanus* and *Sylvilagus floridanus* from several different localities: **a**, *Lepus* cf. *L. americanus* from the Prairie Creek Site (Zone C: 328/1); **b-c**, *Lepus americanus* from Megenity Peccary Cave (Late Pleistocene) in Crawford County, Indiana (b was found in the Batroom crevice, and c was found in Unit M16Q); and **d-e**, *Sylvilagus floridanus* from the Holocene of southern Indiana (R.L. Richards' collection: Lep 11; Lep 24-27.2). Scale in millimeters.

tana (Lundelius, *et al.,* 1983; Richards, 1993b).

### Family Dipodiae: Birch mice, jumping mice, jeroboas
### Subfamily Zapodinae: Jumping mice
### *Zapus hudsonius* (Zimmermann, 1780); Meadow jumping mouse

**Material.** Zone D: LI (2460).

**Remarks.** The meadow jumping mouse occurs sporadically, though often abundantly, throughout most of Indiana. It occurs were there is heavy herbaceous ground cover, usually in old fields (sometimes damp) though also in woodlands. Its most common associates in the fields are the meadow vole (*Microtus pennsylvanicus*) and the masked shrew (*Sorex cinereus*) and in the woodlands are the northern short-tailed shrew (*Blarina brevicauda*) and the white-footed mouse (*Peromyscus leucopus*), all recovered in the Late Pleistocene zone at Prairie Creek.

### Order Lagomorpha: Lagomorphs
### Family Leporidae: Hares and rabbits
### *Lepus* cf. *L. americanus* Erxleben, 1777; Snowshoe hare

**Material.** Zone C: R femur (328/1; Figure 7a).

**Remarks.** *Lepus* material was separated from that of *Sylvilagus* primarily by the slender proportions of the shafts of the humerus, femur, and tibia (Guilday, Parmalee, and Hamilton, 1977) as well as the ulna, radius, and metapodials of *Lepus.* The Prairie Creek femur is larger than that of *Sylvilagus transitionalis, S. floridanus,* and *S. palustris* and smaller than the femora of *Lepus townsendii* and *L. californicus,* falling within the size range of *Lepus americanus* (Table 5). Modern *L. americanus* displays a negative

Table 5. Selected femur measurements of relevant eastern North American Leporids (mm).

| Taxa | Locality | Age | $\bar{x}$[6] | O.R.[7] | N[8] |
|---|---|---|---|---|---|
| | Distal Width of Femur | | | | |
| *Sylvilagus transitionalis*[1] | Massachusetts | Recent | 12.0 | 11.7 - 12.3 | 2 |
| *Sylvilagus floridanus*[3] | North Florida | Recent | 10.9 | 10.4 - 11.3 | 9 |
| *Sylvilagus floridanus*[3] | North Carolina | Recent | 12.9 | 12.8 - 12.9 | 2 |
| *Sylvilagus floridanus*[2] | Indiana | Recent | 13.2 | 12.6 - 14.2 | 15 |
| *Sylvilagus floridanus*[1] | Pennsylvania | Recent | 13.4 | 12.8 - 13.8 | 10 |
| *Sylvilagus palustris*[3] | North Florida | Recent | 13.0 | 11.6 - 14.0 | 9 |
| *Sylvilagus palustris*[3] | North Carolina | Recent | 13.3 | 13.0 - 13.6 | 3 |
| *Lepus americanus*[4] | unspecified | Recent | 12.7 | 11.7 - 13.9 | 5 |
| *Lepus americanus*[1] | New Paris #4, Pennsylvannia | Late Pleistocene | 13.2 | 12.4 - 14.3 | 20 |
| *Lepus americanus*[1] | Clark's Cave, Virginia | Late Pleistocene | 13.4 | 12.3 - 14.5 | 11 |
| *Lepus americanus*[5] | Megenity Peccary Cave, Indiana | Late Pleistocene | 13.5 | 13.2 - 13.7 | 3 |
| *Lepus* cf. *L. americanus* | Prairie Creek, Indiana | Uncertain | 14.4 | 14.4 | 1 |
| *Lepus americanus*[1] | Pennsylvania | Recent | 15.4 | 14.8 - 16.4 | 7 |
| *Lepus californicus*[4] | unspecified | Recent | 16.1 | 15.2 - 16.8 | 9 |
| *Lepus townsendii*[4] | unspecified | Recent | 19.0 | 18.3 - 20.5 | 10 |
| | Greatest Length of Femur from Greater Trochanter | | | | |
| *Sylvilagus floridanus*[3] | North Florida | Recent | 79.5 | 75.0 - 87.4 | 9 |
| *Sylvilagus floridanus*[3] | North Carolina | Recent | 81.8 | 81.0 - 82.6 | 2 |
| *Sylvilagus floridanus*[2] | Indiana | Recent | 84.2 | 79.3 - 88.5 | 14 |
| *Sylvilagus palustris*[3] | North Florida | Recent | 78.4 | 66.0 - 82.0 | 9 |

| Taxa | Locality | Age | $\bar{x}$[6] | O.R.[7] | N[8] |
|---|---|---|---|---|---|
| *Sylvilagus palustris*[3] | North Carolina | Recent | 82.7 | 82.0 - 83.3 | 2 |
| *Lepus americanus*[4] | unspecified | Recent | 89.9 | 84.7 - 96.7 | 5 |
| *Lepus americanus*[5] | Megenity Peccary Cave, Indiana | Late Pleistocene | 93.4 | 92.8 - 94.0 | 2 |
| *Lepus* cf. *L. americanus* | Prairie Creek, Indiana | Uncertain | est. 101.6 | 101.6 | 1 |
| *Lepus californicus*[4] | unspecified | Recent | 108.2 | 100.5 - 114.8 | 9 |
| *Lepus townsendii*[4] | unspecified | Recent | 123.1 | 117.7 - 129.0 | 10 |
| Greatest Length of Femur From Caput | | | | | |
| *Sylvilagus floridanus*[2] | Indiana | Recent | 80.5 | 75.7 - 83.7 | 15 |
| *Lepus americanus*[5] | Megenity Peccary Cave, Indiana | Late Pleistocene | 90.3 | 89.4 - 91.3 | 2 |
| *Lepus* cf. *L. americanus* | Prairie Creek, Indiana | Uncertain | 98.8 | 98.8 | 1 |
| Least Anteroposterior Depth of Shaft | | | | | |
| *Sylvilagus floridanus*[2] | Indiana | Recent | 5.0 | 4.4 - 5.7 | 15 |
| *Lepus americanus*[5] | Megenity Peccary Cave, Indiana | Late Pleistocene | 4.9 | 4.7 - 5.0 | 3 |
| *Lepus* cf. *L. americanus* | Prairie Creek, Indiana | Uncertain | 5.7 | 5.7 | 1 |

[1] Measurements from Guilday, Parmalee, and Hamilton (1977).

[2] Measurements from Richards' collection of modern and sub-recent skeletons from south-central Indiana caves.

[3] Measurements from Holman (1959).

[4] Measurements from Martin (1974); localities not stated.

[5] Measurements from specimens in the collections of the Indiana State Museum.

[6] $\bar{x}$ = Arithmetic mean.

[7] O.R. = Observed range of measurements.

[8] N = Number of specimens.

"Bergman's response" with the smallest average size in the northern part of its range (Guilday, Martin, and McCrady, 1964). *Lepus americanus* fossils from Clark's Cave, Virginia and New Paris #4, Pennsylvania display the smaller size of more northern populations. The Prairie Creek femur is slightly larger than the average size of femora from those two cave sites as well as femora from Megenity Peccary Cave, Indiana, but it is smaller than femora from modern Pennsylvania specimens. There are no modern documented occurrences of *Lepus* in Indiana, though there are some doubtful historical reports for the northwestern part of the State (Lyon, 1936). *Lepus americanus* occurs no nearer to Indiana than Wisconsin and Michigan to the north and the Appalachians to the east, where it inhabits swamps, forests, and thickets (Burt and Grossenheider, 1952). *Lepus americanus* is known from Late Pleistocene strata south (and/or west) of its modern range from Megenity Peccary Cave in Crawford County, Indiana (Richards, unpublished), Welsh Cave in Kentucky (Guilday, Hamilton, and McCrady, 1971), and Crankshaft (Parmalee, Oesch, and Guilday, 1969) and Bat (Hawksley, Reynolds, and Foley, 1973) caves in Missouri. A mixture of *Sylvilagus* and/or *Lepus* remains were identified at the Sangamonian-aged Harrodsburg Crevice in Monroe County, Indiana, but *Sylvilagus* was thought to be the species most likely represented (Parmalee, Munson, and Guilday, 1978). The Prairie Creek femur, of uncertain stratigraphic assignment, and the skeletons from Megenity Peccary Cave are the only records of *Lepus* for Indiana.

### *Sylvilagus* cf. *S. floridanus* (J.A. Allen, 1890); Eastern cottontail

**Material.** Zone D: metatarsal (1408/1).

### Leporidae cf. *Sylvilagus* sp.

**Material.** Zone B: R ulna, prox. end (859/6).

### Leporidae, sp. indet.; cottontail and/or hare

**Material.** Zone D: R dentary with i, p1-m2 (large, 1497/3); L i frag. (D-2461); Lp2 (or m1, m2; D-2693); dens of axis (2335); L humerus, dist. condyle (2335); 2R ulnae, prox. ends (1190/1; 2463: bone #2); R ulna shaft frag. (354/3); frag. R innominate (849/5); R femur, prox. end (large, 1497/4); R tibia, distal end with separate epiphysis (930/1); and L calcaneum (1188/2). Zone C: LM (2597); R dentary with p1-m2 (394/1); lumbar vertebra #7 (374/2); R radius, prox. end (217/3); L astragalus (C-2453); and R calcaneum (subadult, 953/1). Zone B: L dentary frag. with i (1238/1); R dentary with p1-m1 (859/3); Ri (B-2652); Rpl (453/20); Rp2 (or m1, m2, 859/15); L humerus, distal condyle (453/16); L radius, prox. end (859/4); R radius, prox. end (1086/1); R femur, dist. end (766/3); metatarsal, lacking dist. end (453/15); and podial (B-2615).

**Remarks.** Few elements were complete enough to be identified as those of cottontail. The eastern cottontail is often locally abundant in many habitats throughout Indiana but is most numerous in overgrown fields of weeds, briars, and brush. It can also be found in the heavy ground cover around swamps and in open woods. The larger swamp rabbit (*Sylvilagus aquaticus*) found today in the swamps, marshes, and wet bottomlands (Burt and Grossenheider, 1952) of extreme southwestern Indiana could not be identified among the Prairie Creek materials.

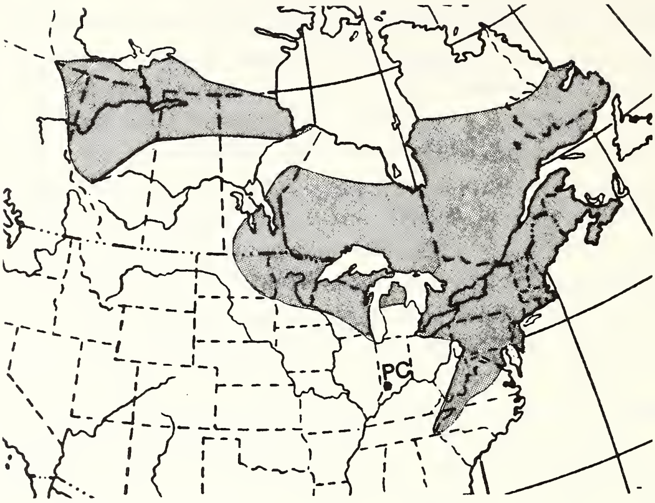

Figure 8. Areas of sympatry (shaded) of Zone D mammals based upon the modern ranges of the star-nosed mole (*Condylura cristata*), the southern red-backed vole (*Clethrionomys gapperi*), and the meadow vole (*Microtus pennsylvanicus*). PC represents the Prairie Creek Site in Daviess County, Indiana.

## DISCUSSION

The Prairie Creek Site small mammal remains represent, for the most part, a natural accumulation in an aquatic environment. There are few, if any, indications of predation or scavenging (e.g., tooth punctures or gnawing) or, in the Holocene zone, of the activities of Native Americans (e.g., cut marks or burning). Stream transport is the likely source of fragmentation, though few elements were worn or notably abraded.

The Late Pleistocene sample (Zone D) represents accumulation in a lake, and the Holocene sample (Zone B) represents accumulation in a marsh and stream environment up to two miles downstream from the lake and more than 10,000 years later in time. Study of the small mammals, per se, did not suggest a selective accumulation of particular species in one environment over the other. Semiaquatic and marsh species such as the star-nosed mole, mink, meadow vole, and muskrat were well represented in both zones (61% in Zone D and 69% in Zone B, collectively by numbers of individuals (MNI)). Other species appear to be of more incidental occurrence. A comparison of the small mammal faunas between Zone D and Zone B reflects, for the most part, faunal associations separated in time by 10,000 years with similar modes of accumulation and conditions of preservation and recovery.

Of the twenty-nine species of small mammals recovered at the Prairie Creek Site, none is extinct, four do not now occur in Indiana (*Microtus xanthognathus,* the yellow-cheeked vole; *Clethrionomys gapperi,* the southern red-backed vole; *Lepus* cf. *L.*

*americanus,* the snowshoe hare; and *Martes pennanti,* the fisher, which occurred historically in Indiana), and two now occur in northern Indiana (*Condylura cristata,* the star-nosed mole, and *Tamiasciurus hudsonicus,* the red squirrel). These extralimital mammals occur primarily in the Late Pleistocene sediments (Zone D) with the star-nosed mole and fisher also occurring in the Holocene strata (Zone B).

The Late Pleistocene zone (Zone D) includes small mammals that support the interpretation (S.T. Jackson and D.R. Whitehead, in prep.) that a spruce-dominated, perhaps open boreal forest surrounded Lake Prairie Creek and its associated marshes and wet meadows. The present areas of sympatry of Zone D extralimital mammals includes centers in northwestern Canada and in the northeastern United States (including the Appalachians and the eastern half of Canada; Figure 8). The presence of *Microtus xanthognathus* suggests that the boreal forests were not particularly dense, and the presence of *M. pennsylvanicus* and *Sylvilagus* cf. *S. floridanus* indicate the occurrence of open areas associated with the lake. Caves in nearby south-central and southeastern Indiana (Richards, 1986) have produced Late Pleistocene associations of boreal voles (*Phenacomys* cf. *P. intermedius,* the heather vole, and *Clethrionomys gapperi,* the southern red-backed vole) with small mammals indicative of open environments (*Spermophilus tridecemlineatus,* the thirteen-lined ground squirrel, and *Geomys bursarius,* the plains pocket gopher). Similar associations from other Late Pleistocene localities suggest a widespread "boreal grassland", an environmental mosaic with patches of open vegetation in the boreal forest (Rhodes, 1984). Perhaps the better open area indicator species were "filtered" from the Prairie Creek deposit by the conifer forests surrounding the more mesic lake. The small mammals recovered at Prairie Creek do not include species indicative of extensive open areas, other than what might be expected in a fluctuating lake environment.

The extralimital yellow-cheeked vole (*Microtus xanthognathus*) and star-nosed mole (*Condylura cristata*) have exclusive (allopatric) distributions today but had areas of overlapping (sympatric) distribution in the Late Pleistocene. The yellow-cheeked vole is also disharmoniously associated with *Blarina brevicauda,* the northern short-tailed shrew, *Scalopus aquaticus,* the eastern mole, *Tamias striatus,* the eastern chipmunk, and *Sylvilagus* cf. *S. floridanus,* the eastern cottontail in the Prairie Creek Late Pleistocene zone. It appears that northern mammals, such as the yellow-cheeked and southern red-backed voles, star-nosed mole, red squirrel, and fisher, were displaced southward by glacial ice, intergrating with resident mammals as suggested by the equable climate model (Graham, 1976; Lundelius, *et al.,* 1983; Semken, 1984). The enhancement of shrew and microtine rodent diversity prevalent in Late Pleistocene cave sites (Graham, 1976) was not reflected in the Prairie Creek sample, suggesting that lacustrine environments in general are not as selective for the accumulation of those mammals as the cave environments are. Although northern fauna did integrate into the resident fauna, there is indication (lack of tree squirrels of the genus *Sciurus,* southern flying squirrel, raccoon, etc.) that some of the resident fauna had migrated away from the approaching glacial ice. This differential response of various species to changing environmental conditions supports current thought on the "individualistic" response of each species (Graham, 1979, 1984; King and Graham, 1981).

The Holocene fauna (Zone B) at the Prairie Creek Site suggests an aquatic or marsh environment in a temperate deciduous woodland. The red squirrel of the Late Pleistocene spruce forest has been replaced by the gray (*Sciurus carolinensis*) and fox (*S. niger*) squirrels, and such temperate woodland mammals as the opossum (*Didelphis virginiana*), flying squirrel (*Glaucomys volans*), pine vole (*Microtus pinetorum*), and raccoon (*Procyon lotor*) are present. Although the star-nosed mole (*Condylura cristata*) and fisher (*Martes pennanti*) still occurred south of their modern range, apparently within their own "individualistic" environmental tolerances, the disharmonious nature of the Late Pleistocene fauna had been dissolved long before the deposition of the Zone B strata. In general, the Prairie Creek Holocene fauna is prevalent in similar environments in Indiana today. The Prairie Creek herpetofauna (Holman and Richards, in prep.) also suggests at least some "individualistic" response to changing environments but presents a dilemma in that several of the reptile species could not exist today in the cooler climates that are suggested by the Zone D pollen.

The lack of several species (e.g., *Lutra canadensis,* the river otter, and *Erethizon dorastum,* the porcupine) in the Prairie Creek strata is attributed to chance in the random sampling of the immense deposit.

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## LITERATURE CITED

Banks, R.C., R.W. McDiarmid, and A.L. Gardner. 1987. Checklist of vertebrates of the United States, the U.S. Territories, and Canada. U.S. Dep. Interior Fish Wildl. Serv. Res. Pub. 166, Washington, D.C., 79 pp.

Blatchley, W.S. and G.H. Ashley. 1901. The lakes of northern Indiana and their associated marl deposits. Indiana Dep. Geol. Natur. Res. Annu. Rep. 25: 31-321.

Burt, W.H. and R.P. Grossenheider. 1964. A field guide to the mammals, second edition. Houghton Mifflin Company, Boston, 284 pp.

Englehardt, D.W. 1965. A late glacial-postglacial pollen chronology for Indiana. Amer. J. Sci. 263: 410-415.

Fraser, G.S. and H.H. Gray. in press. Quaternary evolution of the Prairie Creek Lake Basin, Daviess County, Indiana. Indiana Geol. Surv. Spec. Rep. 53, 20 pp.

Gooding, A.M. and J.G. Ogden III. 1965. A radiocarbon dated pollen sequence from the Wells Mastodon Site near Rochester, Indiana. Ohio J. Sci. 65 (1): 1-11.

Graham, R.W. 1976. Late Wisconsin mammal faunas and environmental gradients of the eastern United States. Paleobiology 2: 343-350.

_______.1979. Paleoclimates and Late Pleistocene faunal provinces in North America. *In:* R.L. Humphrey and D. Stanford (Eds.), *Pre-Llano Cultures of the Americas: Paradoxes and Possibilities,* pp. 46-69, Amer. Anthropol. Assoc., Washington, D.C., 150 pp.

_______. 1984. Paleoenvironmental implications of the Quaternary distribution of the eastern chipmunk (*Tamias striatus*) in central Texas. Quaternary Res. 21: 111-114.

_______, J.A. Holman, and P.W. Parmalee. 1983. Taphonomy and paleoecology of the Christensen Bog mastodon bone bed, Hancock County, Indiana. Illinois State Mus. Rep. Invest. 38, 29 pp.

_______and H.A. Semken, Jr. 1976. Paleoecological significance of the short-tailed shrew (genus: *Blarina*) with a systematic discussion of *Blarina ozarkensis.* J. Mammal. 57: 433-449.

Gray, H.H. 1971. Glacial lake deposits in southern Indiana — Engineering problems in land use. Indiana Geol. Surv. Rep. Progress 30, 15 pp.

Guilday, J.E. 1958. The prehistoric distribution of the opossum. J. Mammal. 39 (1): 39-43.

_______. 1962. The Pleistocene local fauna of the Natural Chimneys, Augusta County, Virginia. Ann. Carnegie Mus. 36: 87-122.

_______. 1971. The Pleistocene history of the Appalachian mammal fauna, Part 3. Vertebrates. *In:* P.C. Holt (Ed.), *The Distributional History of the Biota of the Southern Appalachians,* pp. 233-262, Virginia Polytechnic Inst., Res. Div., Monogr. 4, 306 pp.

_______, H.W. Hamilton, E. Anderson, and P.W. Parmalee. 1978. The Baker Bluff Cave deposit, Tennessee, and the Late Pleistocene faunal gradient. Bull. Carnegie Mus. Natur. Hist. 11: 1-67.

_______, _______, and A.D. McCrady. 1966. The bone breccia of Bootlegger Sink, York County, Pennsylvania. Ann. Carnegie Mus. 38 (8): 145-163.

_______, _______, and _______. 1969. The Pleistocene vertebrate fauna of Robinson Cave, Overton County, Tennessee. Palaeovertebrata 2: 25-75.

_______, _______, and _______. 1971. The Welsh Cave Peccaries (*Platygonus*) and associated fauna, Kentucky Pleistocene. Ann. Carnegie Mus. 43 (9): 249-320.

_______, P.S. Martin, and A.D. McCrady. 1964. New Paris No. 4: A Pleistocene cave deposit in Bedford County, Pennsylvania. Bull. Nat. Speleol. Soc. 26 (4): 121-194.

_______, P.W. Parmalee, and H.W. Hamilton. 1977. The Clark's Cave bone deposit and the Late Pleistocene paleoecology of the central Appalachian Mountains of Virginia. Bull. Carnegie Mus. Natur. Hist. 2: 1-86.

Hall, E.R. 1981. The mammals of North America, second edition. John Wiley and Sons, New York, 1181 pp.

Hallberg, G.R., H.A. Semken, and L.C. Davis. 1974. Quaternary records of *Microtus xanthognathus* (Leach), the yellow-cheeked vole, from northwestern Arkansas and southwestern Iowa. J. Mammal. 55 (3): 640-645.

Hawksley, O., J.F. Reynolds, and R.L. Foley. 1973. Pleistocene vertebrate fauna of Bat Cave, Pulaski County, Missouri. Bull. Nat. Speleol. Soc. 35 (3): 61-87.

Hay, O.P. 1912. The Pleistocene period and its vertebrata. Indiana Dep. Geol. Natur. Res. 36th Annu. Rep. 1911: 541-784.

_______. 1923. The Pleistocene of North America and its vertebrated animals from the states east of the Mississippi River and from the Canadian Province east of longitude 95°. Carnegie Inst. Washington Pub. 322: 1-532.

Hoffmeister, D.F. and C.O. Mohr. 1972. Fieldbook of Illinois mammals. Dover Pub., Inc., New York, 233 pp.

Holman, J.A. 1959. Birds and mammals from the Pleistocene of Williston, Florida. Bull. Florida State Mus. 5: 1-24.

Jackson, S.T., D.R. Whitehead, and G.D. Ellis. 1986. Late glacial and early Holocene vegetational history at the Kolarik Mastodon Site, northwestern Indiana. Amer. Midl. Natur. 115: 361-373.

Johnson, P.C. 1972. Mammalian remains associated with Nebraska Phase earth lodges in Mills County, Iowa. Masters Thesis, Dep. Geol., Univ. Iowa, 77 pp.

Jones, C.A., J.R. Choate, and H.H. Genoways. 1984. Phylogeny and paleobiogeography of short-tailed shrews (Genus *Blarina*). *In:* H.H. Genoways and M.R. Dawson (Eds.), *Contributions in Quaternary Vertebrate Paleontology: A Volume in Memorial to John E. Guilday,* pp. 56-148, Carnegie Mus. Natur. Hist. Spec. Pub. 8, 538 pp.

King, F.B. and R.W. Graham. 1981. Effects of ecological and paleoecological patterns on subsistence and paleoenvironmental reconstructions. Amer. Antiquity 46: 128-142.

Kintner, E. 1930. Notes on unearthing parts of a mastodon skeleton. Proc. Indiana Acad. Sci. 39: 237-239.

Kirkpatrick, C.M. and C.H. Conaway. 1948. Some notes on Indiana mammals. Amer. Midl. Natur. 39 (1): 128-136.

Kurtén, B. and E. Anderson. 1980. Pleistocene mammals of North America. Columbia Univ. Press, New York, 443 pp.

Lundelius, E.L., R.W. Graham, E. Anderson, J. Guilday, J.A. Holman, D.W. Steadmam, and S.D. Webb. 1983. Terrestrial vertebrate faunas. *In:* H.E. Wright, Jr. (Ed.), *Late Quaternary Environments of the United States: Volume I: The Late Pleistocene,* pp. 311-353, Univ. Minnesota Press, Minneapolis, 407 pp.

Lyon, M.W., Jr. 1936. Mammals of Indiana. Amer. Midl. Natur. 17: 1-384.

_______. 1939. Indiana mastodons. Proc. Indiana Acad. Sci. 48: 246-247.

Martin, R.A. 1974. Fossil mammals from the Coleman IIA Fauna, Sumter County. *In:* S.D. Webb (Ed), *Pleistocene Mammals of Florida,* pp. 35-99, Univ. Press Florida, Gainesville, 270 pp.

_______. 1987. Notes on the classification and evolution of some North American fossil *Microtus* (Mammalia: Rodentia). J. Vert. Paleontol. 7(3): 270-283.

Martin, T.J. 1986. A faunal analysis of Fort Ouiatenon, an eighteenth century trading post in the Wabash Valley of Indiana. Ph.D. Thesis, Dep. Anthropol., Michigan State Univ., 520 pp.

Mumford, R.E. 1969. Distribution of the mammals of Indiana. Indiana Acad. Sci. Monogr. 1, 114 pp.

_______ and J.O. Whitaker, Jr. 1982. Mammals of Indiana. Indiana Univ. Press, Bloomington, 537 pp.

Munyer, E.A. 1964. Growth of the appendicular skeleton of the muskrat, *Ondatra z. zibethicus* (Linnaeus). Trans. Illinois Acad. Sci. 57: 243-252.

Nelson, R.S. and H.A. Semken, Jr. 1970. Paleoecological and stratigraphic significance of the muskrat in Pleistocene deposits. Geol. Soc. Amer. Bull. 81: 3733-3738.

Parmalee, P.W. 1967. A recent cave bone deposit in southwestern Illinois. Bull. Nat. Speleol. Soc. 29 (4): 119-147.

_______, P.J. Munson, and J.E. Guilday. 1978. The Pleistocene mammalian fauna of Harrodsburg Crevice, Monroe County, Indiana. Bull. Nat. Speleol. Soc. 40: 64-75.

_______, R.D. Oesch, and J.E. Guilday. 1969. Pleistocene and Recent vertebrate faunas from Crankshaft Cave, Missouri. Illinois State Mus. Rep. Invest. 14, 37 pp.

Purdue, J.R. and B.W. Styles. 1986. Dynamics of mammalian distribution in the Holocene of Illinois. Illinois State Mus. Rep. Invest. 41, 63 pp.

Rand, A.L. and A.S. Rand. 1951. Mammal bones from dunes south of Lake Michigan. Amer. Midl. Natur. 46 (3): 649-659.

Ray, C.E. 1967. Pleistocene mammals from Ladds, Bartow County, Georgia. Bull. Georgia Acad. Sci. 25 (3): 120-150.

Rhodes, R.S., III. 1984. Paleoecology and regional paleoclimatic implications of the Farmdalian Craigmile and Woodfordian Waubonsie mammalian local faunas, southwestern Iowa. Illinois State Mus. Rep. Invest. 40, 51 pp.

Richards, R.L. 1972. The woodrat in Indiana: Recent fossils. Proc. Indiana Acad. Sci. 81: 370-375.

_______. 1982. Hairy-tailed mole (*Parascalops breweri*) remains from south-central Indiana caves. Proc. Indiana Acad. Sci. 91: 613-617.

_______. 1983. Quaternary records of the pygmy and smoky shrews from south-central Indiana caves. Proc. Indiana Acad. Sci. 92: 507-521.

_______. 1984. The Pleistocene vertebrate collection of the Indiana State Museum with a list of the extinct and extralocal Pleistocene vertebrates of Indiana. Proc. Indiana Acad. Sci. 93: 483-504.

_______. 1985. Quaternary remains of the spotted skunk, *Spilogale putorius*, in Indiana. Proc. Indiana Acad. Sci. 94: 657-666.

_______. 1986. Late Pleistocene remains of boreal voles (genera *Phenacomys* and *Clethrionomys*) from southern Indiana caves. Proc. Indiana Acad. Sci. 95: 537-546.

_______. 1993a. Quaternary occurrence of the fisher, *Martes pennanti*, in Indiana. Proc. Indiana Acad. Sci. 98 (in press).

_______. 1993b. Late Pleistocene occurrence of the yellow-cheeked vole (*Microtus xanthognathus*) and northern bog lemming (*Synaptomys borealis*) in southern Indiana. Proc. Indiana Acad. Sci. 98 (in press).

_______ and P.J. Munson. 1988. Flat-headed peccary (*Platygonus*) and recovered Quaternary vertebrate fauna of Indun Rockshelter, Monroe County, Indiana. Bull. Nat. Speleol. Soc. 50: 64-71.

_______, D.R. Whitehead, and D.R. Cochran. 1988. The Dollens Mastodon (*Mammut americanum*) locality, Madison County, east-central Indiana. Proc. Indiana Acad. Sci. 97: 571-581.

Sanford, J.T. 1935. The Richmond mastodon. Proc. Rochester Acad. Sci. 7: 137-156.

Semken, H.A., Jr. 1966. Stratigraphy and paleontology of the McPherson *Equus* beds (Sandahl local fauna), McPherson County, Kansas. Univ. Michigan Mus. Paleontol. Contrib. 20: 121-178.

_______. 1984. Paleoecology of a Late Wisconsinan/Holocene micromammal sequence in Peccary Cave, northwestern Arkansas. *In:* H.H. Genoways and M.R. Dawson (Eds.), *Contributions in Quaternary Vertebrate Paleontology: A Volume in Memorial to John E. Guilday,* pp. 405-431, Carnegie Mus. Natur. Hist. Spec. Pub. 8, 538 pp.

Simpson, P.F. 1934. The Garrett mastodont. Proc. Indiana Acad. Sci. 34: 154-155.

Tomak, C.H. 1975. Prairie Creek: A stratified site in southwestern Indiana. Proc. Indiana Acad. Sci. 84: 65-68.

_______. 1982. *Dasypus bellus* and other extinct mammals from the Prairie Creek Site. J. Mammal. 63 (1): 158-160.

Whitehead, D.R., S.T. Jackson, M.C. Sheehan, and B.W. Leyden. 1982. Late-glacial vegetation associated with caribou and mastodon in central Indiana. Quaternary Res. 17: 241-257.

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# NEW ICHTHYOFAUNAL RECORDS FOR THE CALUMET, KANKAKEE, AND IROQUOIS DRAINAGES OF INDIANA

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ABSTRACT: Field collections during July and August 1990 resulted in new distributional records for 13 fishes within the Calumet, Kankakee, and Iroquois River drainages of Indiana. Species previously unknown from the entire State include *Salmo salar, Notropis dorsalis,* and *Campostoma oligolepis.* New species records for northwestern Indiana include: *Etheostoma chlorosoma, Percina maculata, Pimpehales promelas,* and *Lampetra appendix* from the Calumet River drainage; *Lampetra aepyptera* and *Cyprinella whipplei* from the Kankakee River drainage; and *Moxostoma valenciennesi* and *Cyprinella lutrensis* for the Iroquois River drainage. Range extensions were documented for *L. appendix, Moxostoma duquesnei,* and *E. chlorosoma* in the Kankakee River drainage.

## INTRODUCTION

In an effort to document the current distribution of Indiana fish species, a checklist of the vertebrate species of Indiana was compiled, which documented several new records of fishes from the State (Simon, *et al.,* 1992). In order to elucidate species occurrence and distributional trends, new records from the northwestern portion of the State were discovered during current evaluations of the Central Corn Belt Plain Ecoregion (Simon, 1991).

The surveys were conducted to develop biological criteria for the State of Indiana in the Central Corn Belt Plain Ecoregion. This survey is the most recent in a series of collections published for northwestern Indiana (Meek and Hildebrand, 1910; Gerking, 1945) and the adjacent upper Illinois River basin (Forbes and Richardson, 1920; Smith, 1979; Simon, 1990). The purpose of this study is to document newly discovered species, distributional trends, and present locality information for the 13 species present in northwestern Indiana.

## METHODS AND MATERIALS

Sampling was conducted at 197 stations during the summer of 1990 during basin surveys of the Calumet, Kankakee, and Iroquois River drainages (Figure 1) in the Central Corn Belt Plain Ecoregion: 112 stations in the Kankakee basin, 37 in the Iroquois basin, and 48 in the Calumet basin. Some stations were selected based on historic collection efforts, and equal effort was attributed to each of the three basins based on total drainage area. At each location, a representative sample was collected from each of the available habitats within a longitudinal distance 15 times the river width up to a maximum of 500 m. The specimens were collected either by wading or from a boat using various sized 1/8 inch mesh minnow seines or pulsed DC electroshocking gear (T&J Model 1780 DCV, capable of 300 volt output). Voucher specimens of all species are available for inspection by professional ichthyologists.

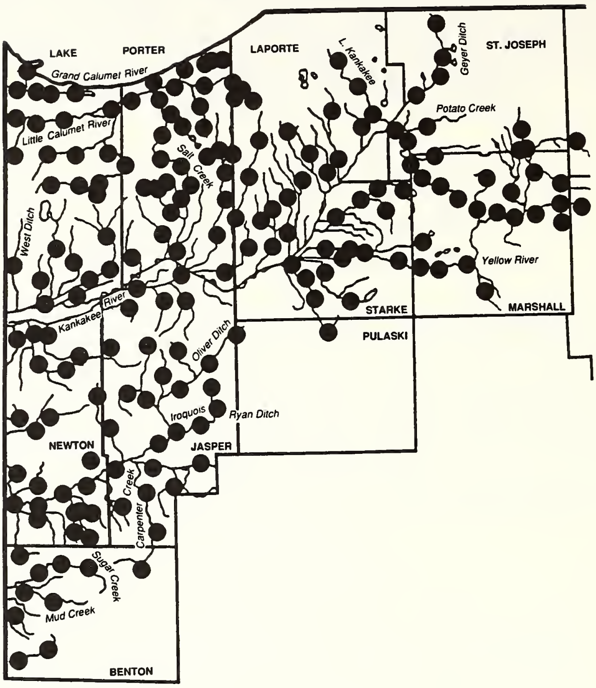

Figure 1. Location of 197 Central Corn Belt Plain Ecoregion sites within the political boundaries of Indiana for 1990 sampling in the Calumet, Kankakee, and Iroquois River drainages.

## DISCUSSION

***Campostoma oligolepis.*** The large scale stoneroller has gone unrecognized in Indiana even though extensive sampling has been conducted in the northwestern portion of the State. The species is recorded in Illinois from the upper Illinois River basin including the Fox River, mainstem Illinois River, and the Des Plaines River (Burr, 1980). This species appears to be abundant and more widely distributed in the northern part of the State than *Campostoma anomalum,* occurring throughout the major drainages of northwestern Indiana and in the headwaters of the Wabash, the St. Joseph of Lake Michigan, and Maumee River basins.

***Cyprinella lutrensis.*** The red shiner has migrated across the Mississippi River basin displacing or hybridizing with other *Cyprinella* (Larimore and Smith, 1963). The red shiner originally was reported from Illinois during observed hybridization swarms with *Cyprinella spiloptera* (Page and Smith, 1970). It was reported from the upper Illinois basin by Matthews (1980). No record of the species had been documented in Indiana, although the species may have been present for many years. It is extremely tolerant and capable of residing under low dissolved oxygen and degraded habitat conditions (pers. obs.).

Table 1.New fish species records in northwestern Indiana.

| Species | Drainage System | County | Num. of Specimens | Collecting Sites |
|---|---|---|---|---|
| *Campostoma oligolepis* | Kankakee River | Lake | 10 | West Creek, 1.9 miles southwest of Belshaw, West Creek Township (Sec. 7/18, T32N, R9W) |
| | | | 3 | Spring Run of Greisel ditch, 3 miles east of Lowell, Cedar Creek Township (Sec. 29, T33N, R8W) |
| | | | 7 | East Branch Stony Run ditch, 2 miles south of LeRoy, Winfield Township (Sec. 5, T33N, R7W) |
| | | Porter | 73 | Cornell ditch, 4.75 miles east of Hebron, Boone Township (Sec. 9, T33N, R6W) |
| | | | 4 | Wolf Creek, 4 miles northeast of Kouts, Porter Township (Sec. 28, T34N, R6W) |
| | | | 5 | Cobb ditch, 2 miles north-northeast of Kouts, Porter Township (Sec. 35, T34N, R6W) |
| | | | 26 | Crooked Creek, 2 miles northeast of Kouts, Morgan Township (Sec. 33, T34N, R5W) |
| | | | 36 | Crooked Creek, 5 miles east-southeast of Valparaiso, Morgan Township (Sec. 10, T34N, R5W) |
| | | LaPorte | 4 | Slocum ditch, Wanatah, Clinton Township (Sec. 32, T35N, R4W) |
| | | Marshall | 8 | Yellow River, 4.5 miles south of Plymouth, Center Township (sec. 31, T33N, R2E) |
| | | | 27 | Yellow River, 4.5 miles southwest of Plymouth, Union Township (Sec. 35, T33N, R1E) |
| | | | 2 | Crews ditch, 5 miles east of Plymouth, Center Township (Sec. 12, T38N, R2E) |

| Species | Drainage System | County | Num. of Specimens | Collecting Sites |
|---|---|---|---|---|
| | | | 23 | Wolf Creek, 4.75 miles south of Plymouth, Center Township (Sec. 33, T33N, R2E) |
| | | | 2 | Yellow River, 2.25 miles north of Breman, German Township (Sec. 22, T35N, R3E) |
| | | Starke | 3 | Yellow River, 4 miles west of Knox, Center Township (Sec. 18, T33N, R2W) |
| | | | 1 | Yellow River, 5 miles east of Knox, Washington Township (Sec. 27/28, T33N, R1W) |
| | | | 3 | Craigmile ditch, 4 miles southwest of Knox, Wayne Township (Sec. 1, T32N, R3W) |
| | | Kosciusko | 2 | Dausman ditch, 4.75 miles south of Nappanee, Scott Township (Sec. 29,T34N, R5E) |
| | | Elkhart | 20 | Lateral ditch No. 5 (Lost Creek), 3.5 miles northwest of Napanee, Locke Township (Sec. 11, T35N, R4E) |
| | | Jasper | 10 | Bice ditch, 4.75 miles south of Rensselaer, Milroy Township (Sec. 22, T28N, R6W) |
| | | | 18 | Carpenter Creek, 0.75 miles northwest of Egypt, Jordan Township (Sec.22, T28N, R7W) |
| | Iroquois River | Newton | 11 | Hunter ditch, 6.5 miles northeast of Kentland, Grant Township (Sec. 10, T27N, R8W) |
| | | | 8 | Darroch ditch, 5.5 miles east of Kentland, Grant Township (Sec. 21, T27N, R8W) |
| | | | 139 | Darroch ditch, 7.5 miles northeast of Kentland, Grant Township (Sec. 9, T27N, R8W) |

| Species | Drainage System | County | Num. of Specimens | Collecting Sites |
|---|---|---|---|---|
| | | | 40 | Montgomery ditch, 2.75 miles northeast of Kentland, Jefferson Township (Sec. 12, T27N, R9W) |
| | | | 30 | Montgomery ditch, 2.5 miles northwest of Kentland, Jefferson Township (Sec. 8, T27N, R9W) |
| | | | 18 | Whaley ditch, 5.75 miles northwest of Kentland, Washington Township (Sec.23, T28N, R10W) |
| | | | 1 | Hickory Branch, 1.6 miles northeast of Brook, Iroquois Township (Sec.9, T28N, R8W) |
| | | Jasper | 1 | Bruner ditch, 7.5 miles north of Rensselear, Union Township (Sec. 18, T30N, R6W) |
| | | Benton | 1 | Leuck ditch, 7 miles southwest of Fowler, Hickory Grove Township (Sec. 20, T24N, R9W) |
| | | | 2 | Mud Creek, 4.5 miles southwest of Earl Park, Parish Grove Township (Sec. 6, T26N, R9W) |
| | | | 118 | Sugar Creek, 4 miles southwest of Earl Park, York Township (Sec. 31, T26N, R9W) |
| | | | 26 | Bonham ditch, 4 miles northwest of Earl Park, York Township (Sec. 6, T26N, R9W) |
| | | | 19 | Sugar Creek, 4 miles east of Earl Park, Richland Township (Sec. 17, T26N, R8W) |
| | | | 195 | Sugar Creek, 0.5 miles north of Earl Park, Richland Township (Sec. 14, T26N, R9W) |
| | | | 3 | Carpenter Creek, 5 miles south of Remington, Gilboa Township (Sec. 11, T26N, R7W) |

| Species | Drainage System | County | Num. of Specimens | Collecting Sites |
|---|---|---|---|---|
| | | | 25 | Curtis Creek, 5.5 miles west of Rensselear, Newton Township (Sec. 19, T29N, R7W) |
| *Cyprinella lutrensis* | Kankakee River | Marshall | 2 | Yellow River, 7.5 miles southwest of Plymouth, Union Township (Sec. 31, T33N, R1E) |
| | | Starke | 21 | Yellow River, 4 miles west of Knox, Center Township (Sec. 18, T33N, R2W) |
| | Iroquois River | Newton | 12 | Iroquois River, 2 miles east of Brooks, Iroquois Township (Sec. 15, T28N, R8W) |
| | | | 11 | Iroquois River, 2.75 miles northeast of Kentland, Washington Township (Sec. 25, T28N, R9W) |
| | | | 8 | Iroquois River, 4 miles northwest of Kentland, Jefferson Township (Sec. 1, T27N, R10W) |
| | | | 1 | Whaley ditch, 5.75 miles northwest of Kentland, Washington Township (Sec. 23, T28N, R10W) |
| *Cyprinella whipplei* | Kankakee River | Porter | 2 | Crooked Creek, 2 miles northeast of Kouts, Morgan Township (Sec. 33, T34N, R5W) |
| | | Marshall | 2 | Yellow River, 7.5 miles southwest of Plymouth, Union Township (Sec.31, T33N, R1E) |
| | Iroquois River | Newton | 8 | Iroquois River, 2.75 miles northeast of Kentland, Washington Township (Sec. 35, T28N, R9W) |
| | | | 7 | Iroquois River, 4 miles northwest of Kentland, Jefferson Township (Sec. 1, T27N, R10W) |
| | | | 1 | Whaley ditch, 5.75 miles northwest of Kentland, Washington Township (Sec. 23, T28N, R10W) |

| Species | Drainage System | County | Num. of Specimens | Collecting Sites |
|---|---|---|---|---|
| | | | 1 | Beaver Creek, 3.25 miles west of Morocco, Beaver Township (Sec.24/19, T29N, R10/9W) |
| *Etheostoma chlorosma* | Calumet River | Lake | 1 | Deep River, 2 miles north of Hobart, Hobart Township (Sec. 20, T36N, R7W) |
| | Kankakee River | Lake | 1 | West Creek, 2 miles northwest of North Hayden, West Creek Township (Sec. 13/24, T33N, R10W) |
| | | | 1 | Cedar Creek, 3 miles south of Lowell, Cedar Creek Township (Sec. 2, T32N, R9W) |
| | | LaPorte | 1 | Pitner ditch, 0.5 miles north of Lomax near mouth with Kankakee River, Dewey Township (Sec. 4, T32N, R4W) |
| *Lampetra aepyptera* | Kankakee River | Laporte | 2 | Waltham ditch, 2.5 miles north-northeast of Hanna, Noble Township (Sec. 26/35, T35N, R3W) |
| | | | 1 | Little Kankakee River, 2 miles south of Fish Lake, Lincoln Township (Sec. 30, T36N, R1WS) |
| | | St. Joseph | 2 | Pine Creek, 3 miles north of Walkerton, Lincoln Township (Sec. 11,T35N, R1W) |
| *Lampetra appendix* | Calumet River | Laporte | 10 | Reynold's Creek, 1.5 miles west of Highway 421 and US 80/90 intersection, New Durham Township (Sec. 6, T36N, R4W) |
| | | | 2 | Reynold's Creek, 8.5 miles west of LaPorte, Spring Township (Sec. 32, T37N, R4W) |
| | Kankakee River | Laporte | 3 | Mill Creek, 6 miles southwest of LaPorte, Scipio Township (Sec. 32, T36N, R3W) |

| Species | Drainage System | County | Num. of Specimens | Collecting Sites |
|---|---|---|---|---|
| | | | 2 | Waltham ditch, 2.5 miles north-northeast of Hanna, Noble Township (Sec. 26/35, T35N, R3W) |
| | | | 1 | Kingsbury ditch, 2 miles north of Kingsbury Heights, Washington Township (Sec. 6,T35N, R2W) |
| | | | 8 | Little Kankakee River, 7.5 miles southeast of LaPorte, Lincoln Township (Sec. 18, T36N, R1W) |
| | | St. Joseph | 10 | Pine Creek, 3 miles north of Walkerton, Lincoln Township (Sec. 11, T35N, R1W) |
| | | Marshall | 1 | Yellow River, 4.5 miles southwest of Plymouth, Union Township (Sec. 35, T33N, R1E) |
| | | | 4 | Yellow Bank Creek, 1 mile northwest of Teegarden, Polk Township (Sec. 22, T35N, R1E) |
| | | | 2 | Peter Saber ditch, 1 mile north of Tyner, Polk Township (Sec. 4, T34N, R1E) |
| | | Starke | 1 | Robbins ditch, 0.75 miles northwest of Koontz Lake, Oregon Township (Sec. 2/11, T34N, R1W) |
| | | | 2 | Yellow River, 5 miles east of Knox, Washingtn Township (Sec. 27/28, T33N, R1W) |
| *Moxostoma duquesnei* | Kankakee River | Marshall | 1 | Dausman Ditch, 5 miles southeast of Bremen, Bourbon Township (Sec. 29, T34N, R4E) |
| | | | 2 | Yellow River, 7.5 miles southwest of Plymouth, Union Township (Sec. 31, T33N, R1E) |
| | Iroquois River | Benton | 2 | Sugar Creek, 4 miles east of Earl Park, Richland Township (Sec. 17, T26N, R8W) |

| Species | Drainage System | County | Num. of Specimens | Collecting Sites |
|---|---|---|---|---|
| *Moxostoma valenciennesi* | Iroquois River | Jasper | 1 | Oliver ditch, 2 miles west of Lewiston, Barkley Township (Sec. 14, T30N, R6W) |
| *Notropis dorsalis* | Kankakee River | Lake | 4 | Kankakee River, 1 mile southeast of Shelby, Eagle Creek Township (Sec. 34, T32N, R8W) |
| *Percina maculata* | Calumet River | Porter | 1 | Little Calumet River, Porter, Westchester Township (Sec. 34, T37N, R6W) |
| *Phoxinus erythrogaster* | Kankakee River | Porter | 1 | West Branch of Crooked Creek, 4 miles east of Valparaiso, Washington Township (Sec. 10, T35N, R5W) |
| *Pimephales promelas* | Calumet River | Lake | 7 | Deer Creek, 1 mile southeast of Merrillville, Ross Township (Sec. 31, T35N, R7W) |
| | | | 34 | Main Beaver Dam ditch, 1.5 miles east of Crown Point, Center Township (Sec. 4, T34N, R8W) |
| | | | 4 | Main Beaver Dam ditch, 1.25 miles north of Crown Point. (Sec. 32, T35N, R8W) |
| | | | 2 | Dyer Ditch, 1.5 miles east of Dyer, St. John Township (Sec. 7/18, T35N, R9W) |
| | | | 23 | Little Calumet River, Lake Station, Calumet Township (Sec. 9, T36N, R7W) |
| | | | 1 | Little Calumet River, Munster, North Township (Sec. 19, T36N, R9W) |
| | | | 1 | Grand Calumet River, East Chicago, North Township (Sec. 5, T36N, R9W) |
| | | Porter | 5 | Burns Ditch, Ogden Dunes, Ogden Dunes Township (Sec. 36/25, T36/37N, R7W) |

| Species | Drainage System | County | Num. of Specimens | Collecting Sites |
|---|---|---|---|---|
| | | | 2 | Little Calumet River, 1.5 miles west of Portage, Portage Township (Sec. 2, T36N, R7W) |
| | | | 3 | Salt Creek, 1.5 miles east of Portage, Portage Township (Sec. 5/6, T36N, R6W) |
| | | | 1 | Sager Creek, 1 mile south of Valparaiso, Center Township (Sec. 25, T35N, R6W) |
| | | | 2 | Sand Creek, 1 mile northeast of Chesterton, Westchester Township (Sec. 32, T37N, R5W) |
| *Salmo salar* | Calumet River | Porter | 1 | Little Calumet River, 3.75 miles south of Pines, Pine Township (Sec. 25, T37N, R5W) |
| | | Laporte | 5 | Reynold's Creek, 1.5 miles west of State Road 421 and US 80/90 intersection, New Durham Township (Sec. 6, T36N, R4W) |
| | Kankakee River | St. Joseph | 1 | Geyer ditch, 5.3 miles east of New Carlisle, Warren Township (Sec. 10, T37N, R1E) |

***Cyprinella whipplei.*** The only upper Illinois River basin collection records of the steelcolor shiner have been from the lower Yellow River, Starke County (Gilbert and Burgess, 1980). The species is rare in the Kankakee, in spite of being collected from several of its northern tributaries, but it is more common in the Iroquois River and tributaries.

***Etheostoma chlorosoma.*** The bluntnose darter historically occurred in Wolf Lake, Cook County, Illinois (Meek and Hildebrand, 1910; Forbes and Richardson, 1920) but has been considered extirpated from the Calumet basin due to industrialization (Smith, 1979). A single specimen from Deep River above the Lake George dam is the first record of the bluntnose darter from the Calumet basin in 80 years and is the furthest northern report in Indiana. Additional collections from the Kankakee River indicate that the species is more widely distributed than previously believed.

***Lampetra aepyptera.*** The least brook lamprey has never been reported from the upper Illinois River basin (Rhode and Jenkins, 1980). The nearest known Indiana location was a tributary of the middle Wabash River in Vigo County. The three newly reported locations (Table 1) represent the northern limit of distribution of the least brook lamprey in Indiana. Although the small number of lamprey specimens collected indicates that the species has always been rare, many historic collections may have been deficient in lamprey specimens due to the selectivity of the collecting equipment used.

***Lampetra appendix.*** The American brook lamprey has a wide-ranging distribution centered around the Great Lakes. It has previously been recorded from three Kankakee River drainage locations in Indiana (Gerking, 1945; Rohde, 1980) but not from any Lake Michigan tributary waters in Indiana. The species may be more common than previously recognized as evidenced by the additional locations discovered in the Kankakee River drainage. Further efforts to collect lampreys should be a priority, since the absence of lampreys from most ichthyological surveys reduces our knowledge of these organisms over most of their range.

***Moxostoma duquesnei.*** The black redhorse had been recorded from only a single tributary location (Gerking, 1945) and at several additional mainstem localities in the upper Kankakee River (Jenkins, 1980). It is widely distributed in the adjacent Illinois portion of the basin but has not previously been recorded from the Iroquois River drainage in Illinois (Smith, 1979) or Indiana (Gerking, 1945; Jenkins, 1980).

***Moxostoma valenciennesi.*** The greater redhorse has only recently been documented in the upper Illinois River at RM 249, Illinois, with a single specimen collected from a 1985 survey (Seegert, 1986). The species has not been reported previously from the Kankakee or Iroquois basins of Indiana (Gerking, 1945).

***Notropis dorsalis.*** The bigmouth shiner is common in the streams and small rivers of Illinois, and it entered Indiana through the Kankakee River. Gerking (1955) indicated that the only other previously known record was from an unknown location near South Bend and was probably doubtful. The location where the bigmouth shiner was collected (Table 1) occurs just over the Illinois-Indiana State line and represents the only extant record with vouchered specimens among a large number of collections from northern Indiana (Nelson and Gerking, 1968). Trautman (1957) suggested that the disjunct distribution of this species is due to the past expansion and subsequent retreat of the dry prairie habitat it prefers.

***Percina maculata.*** The blackside darter is widely distributed throughout the Kankakee River and adjacent drainages but has never been recorded from either of the Calumet River basins of Indiana. The species previously occurred in the Trail Creek drainage (Gerking, 1945), a tributary of Lake Michigan near Michigan City, but its current status is unknown. The record from the Little Calumet River is the first record of this species from the Indiana portion of the basin.

***Phoxinus erythrogaster.*** The southern redbelly dace had not been previously reported from the Kankakee River drainage, but it has been documented from the Calumet, White, Wabash, and Ohio River drainages (Meek and Hildebrand, 1910; Nelson and Gerking, 1968). The species occurs in the adjacent portion of the Kankakee drainage in Illinois (Starnes and Starnes, 1980).

***Pimephales promelas.*** Although the fathead minnow is a ubiquitous species often occurring in greatest abundance in degraded pools of small to moderate sized streams, it has not been previously documented from the Calumet drainage of Indiana (Gerking, 1945; Lee and Shute, 1980). The species was usually represented by a few individuals from marginal habitat in low-gradient streams and creeks, such as the Grand Calumet and tributaries of the Little Calumet Rivers.

***Salmo salar.*** The earliest stocking attempts of coho, chinook, and Atlantic salmon into tributaries of the Great Lakes during the 1800's proved futile. Beginning in the 1970's, Atlantic salmon were successfully stocked after multiple attempts into Lake Michigan tributaries by the State of Michigan Department of Natural Resources (Becker, 1983). No previous record of Atlantic salmon from the inland waters of Indiana has been recorded, and no intentional stocking of the species had been planned (T. Lauer, pers. comm.). The specimen recorded from the Kankakee River drainage was obviously introduced, since the only dispersal route would have required the individual to migrate through the Illinois Canal system up the Kankakee River. Specimens in the Little Calumet River basin may have been from disrupted migration from Lake Michigan stocking efforts.

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## LITERATURE CITED

Becker, G.C. 1983. Fishes of Wisconsin. Univ. Wisconsin Press, Madison, 1052 pp.

Burr, B.M. 1980. *Campostoma oligolepis. In:* D.S. Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. (Eds.), *Atlas of North American Freshwater Fishes,* p. 145, North Carolina State Mus. Natur. Hist. Spec. Pub. 1980-12, 867 pp.

Forbes, S.A. and R.E. Richardson. 1920. The fishes of Illinois, 2nd Ed. Illinois Natur. Hist. Surv., Urbana, 357 pp.

Gerking, S.D. 1945. The distribution of the fishes of Indiana. Investigations Indiana Lakes Streams 3(1): 1-137.

__________. 1955. Key to the fishes of Indiana. Investigations Indiana Lakes Streams 4: 49-86.

Gilbert, C.R. and W.H. Burgess. 1980. *Notropis whipplei. In:* D.S. Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. (Eds,), *Atlas of North American Freshwater Fishes,* p. 324, North Carolina State Mus. Natur. Hist. Spec. Pub. 1980-12, 867 pp.

Jenkins, R.E. 1980. *Moxostoma duquesnei. In:* D.S. Lee, *et al.* (Eds.), *Atlas of North American Freshwater Fishes,* pp. 419- 420, North Carolina State Mus. Natur. Hist. Spec. Pub. 1980- 12, 867 pp.

Lee, D.S. and J.R. Shute. 1980. *Pimephales promelas. In:* D.S. Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. (Eds.), *Atlas of North American Freshwater Fishes,* p. 341, North Carolina State Mus. Natur. Hist. Spec. Pub. 1980-12, 867 pp.

Matthews, W.J. 1980. *Notropis lutrensis. In:* D.S. Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. (Eds.), *Atlas of North American Freshwater Fishes,* p. 285, North Carolina State Mus. Natur. Hist. Spec. Pub. 1980-12, 867 pp.

Meek, S.E. and S.F. Hildebrand. 1910. A synoptic list of the fishes known to occur within fifty miles of Chicago. Field Mus. Natur. Hist. Zool. Ser. Pub. 142 7(9): 223-338.

Nelson, J.S. and S.D. Gerking. 1968. Annotated key to the fishes of Indiana. Indiana Aquatic Research Unit, Indiana Univ., Bloomington, Indiana, 84 pp.

Page, L.M. and P.W. Smith. 1970. Recent range adjustments and hybridization of *Notropis lutrensis* and *Notropis spilopterus* in Illinois. Trans. Illinois State Acad. Sci. 63: 264-272.

Rohde, F.C. 1980. *Lampetra appendix. In:* D.S. Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. (Eds.), *Atlas of North American Freshwater Fishes,* p. 23, North Carolina State Mus. Natur. Hist. Spec. Pub. 1980-12, 867 pp.

________ and R.E. Jenkins. 1980. *Lampetra aepyptera. In:* D.S. Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. (Eds.), *Atlas of North American Freshwater Fishes,* p. 21, North Carolina State Mus. Natur. Hist. Spec. Pub. 1980-12, 867 pp. Seegert, G. 1986. Rediscovery of the greater redhorse (*Moxostoma valenciennesi* Jordan) (Cypriniformes: Catostomidae) in Illinois. Trans. Illinois State Acad. Sci. 79: 293-294.

Simon, T.P. 1990. Instream water quality evaluation of the upper Illinois River basin using the index of biotic integrity. *In:* W.S. Davis (Ed.), *Proceedings of the Midwest Pollution Control Biologists Meeting,* pp. 124-142, U.S. Environ. Protection Agency, Region V, Environmental Sci. Div., Chicago, Illinois, EPA 905/9-90/005.

________. 1991. Development of index of biotic integrity expectations for the ecoregions of Indiana. I. Central corn belt plain. U.S. Environmental Protection Agency, Environmental Sci. Div., Central Regional Lab., Chicago, Illinois, EPA 905/9-91/025.

________, J.O. Whitaker, Jr., J.S. Castrale, and S.A. Minton. 1992. Checklist of the vertebrate species of Indiana. Proc. Indiana Acad. Sci. 101 (1-2):.

Smith, P.W. 1979. Fishes of Illinois. Univ. Illinois Press, Champaign, 314 pp.

Starnes, W.C. and L.B. Starnes. 1980. *Phoxinus erythrogaster. In:* D.S. Lee, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. (Eds.), *Atlas of North American Freshwater Fishes,* p. 337, North Carolina State Mus. Natur. Hist. Spec. Pub. 1980-12, 867 pp.

Trautman, M.B. 1957. The Fishes of Ohio. Ohio State Univ.Press, Columbus, 638 pp.

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# WINTER FOOD HABITS OF THE ORANGETHROAT DARTER, *ETHEOSTOMA SPECTABILE,* FROM SOUTHWESTERN INDIANA

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ABSTRACT: The winter diet and food item selectivity of the orangethroat darter (*Etheostoma spectabile*) were studied in the lower Wabash River drainage of southwestern Indiana. Major components of the diet were chironomid larvae and isopod crustacea, with trichopteran larvae and amphipod crustacea taken incidentally. Orangethroat darters positively selected for chironomid larvae when overall prey densities were high but were less selective for this taxon when prey densities were low. Isopod crustacea were preyed upon at the same rate in which they occurred in the environment when prey densities were low and were avoided when prey densities were high. These actions suggest that food item selectivity in the orangethroat darter may be influenced by prey availability.

## INTRODUCTION

The orangethroat darter, *Etheostoma spectabile,* is commonly found inhabiting unsilted streams throughout midwestern North America. It is rare in the lower Wabash drainage of Illinois, Indiana, and in neighboring Kentucky (Nelson and Gerking, 1968; Burr and Warren, 1986; Cummings, pers. comm.), due to the lack of suitable habitat (Kozel, *et al.,* 1981; Grannan and Lodato, 1986). However, a small isolated population occurs in a first order tributary of the Wabash River in Posey County, Indiana (Grannan and Lodato, 1986). This stream provides a locally rare habitat (i.e., an unsilted headwater stream) and offers an opportunity to study the feeding ecology of *E. spectabile* in a relatively simple and isolated system. Although seasonal changes in the diets and food item electivity of various darters have been examined (Small, 1975; Hlohowskij and White, 1983; Martin, 1984; Fisher and Pearson, 1987), most studies have focused on competitive interactions. Relatively few studies concerning darter food habits have addressed how changes in the density of the populations comprising the resource base might influence food item selection (but see Hansen, *et al.,* 1986). This study was undertaken in order to investigate the winter food habits and food item selectivity relative to food item density of a locally rare species.

## METHODS

Road Brook is a first order tributary of the Wabash River located 7 km south of New Harmony, Indiana. The stream drains approximately 3.0 km$^2$ of hardwood forests within Harmonie State Park. Shallow raceways with fine sand substrates are the predominant habitat in Road Brook, although deeper pools are occasionally found. Stream width throughout the 1 km run varies from 1 to 3 m and ranges in depth from 5 cm to 75 cm. The only other darter species occurring in Road Brook is the spottail darter, *Etheostoma squamiceps* (Grannan and Lodato, 1986).

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Table 1. Stomach contents and electivity indices (E) for specific food items of *Etheostoma spectabile* in Road Brook by month of collection. Percent contribution to diet by food item is followed parenthetically by average number of items per darter.

| Taxa | December | E | February | E |
|---|---|---|---|---|
| Isopoda | | | | |
| *Caecidotea* | 43.5 (2.4) | 0.02 | 12.2 (1.5) | -0.49 |
| Amphipoda | | | | |
| *Gammarus* | 5.7 (0.3) | 0.23 | 4.1 (0.5) | 0.04 |
| Trichoptera | | | | |
| *Lepidostoma* | 7.5 (0.4) | 0.61 | 2.4 (0.3) | -0.14 |
| Chironomidae | 35.8 (1.9) | -0.10 | 78.9 (9.7) | 0.2 |
| Copepoda | 5.7 (0.3) | nc | nc | |
| Oligochaeta | nc | nc | 2.4 (0.3) | 0.04 |

nc = Not consumed or collected.

Collections were made on 20 December 1990 and 22 February 1991. Darters were collected between 12:00 and 15:00 CST from sand raceways with a 1.7 m seine with 4 mm mesh, preserved immediately in 10% formalin, and brought to the lab for stomach content analysis. Only ten darters were collected each sampling period as a precaution against disturbing the apparently small population. The validity of using such small samples was tested by calculating the cumulative diversity (Shannon's H) of successively summed stomach content samples following Hurtubia (1973) and Miller (1983). All darters collected were age 1+ (standard length, SL > 35 mm).

Immediately after each collection, the benthic community was sampled to estimate the structure of the resource base and the relative density of prey populations. Ten Surbur samples were taken at the collection site and preserved in 10% formalin. Stomach contents and benthic samples were identified to the lowest practical taxon following Pennak (1989) and Merritt and Cummins (1984).

Percent frequency of dietary and resource base components were used to determine the selectivity of *E. spectabile* for specific taxa with Ivlev's (1961) electivity index (E),

$$E = (r - p)/(r + p),$$

where r is the proportion of the diet comprised of a taxon and p is the proportion of the resource base attributable to the same taxon. Values range from 1.00, when the taxon is

Table 2. Resource base of *Etheostoma spectabile* in Road Brook by month of collection. Percent contribution to resource base is followed parenthetically by average density per $m^2$.

| Taxa | December | February |
|---|---|---|
| Isopoda | | |
| *Caecidotea* | 41.8 (25.5) | 36.1 (240.0) |
| Amphipoda | | |
| *Gammarus* | 3.6 (2.2) | 3.8 (24.4) |
| Trichoptera | | |
| *Lepidostoma* | 1.8 (1.1) | 3.2 (20.0) |
| Chironomidae | 43.6 (26.6) | 53.1 (336.6) |
| Ceratopogonidae | 1.8 (1.1) | 0.8 (4.4) |
| Tipulidae | 1.8 (1.1) | 0.3 (2.2) |
| Tabanidae | 1.8 (1.1) | 0.3 (2.2) |
| Libellulidae | 1.8 (1.1) | 0.2 (1.1) |
| Oligochaeta | nc | 2.2 (14.4) |
| Total Density | 59.8 | 645.3 |

nc = Not collected.

being selected for positively, to -1.00, when the taxon is being selected against or avoided. A value of 0.00 indicates that the prey taxon occurs in the same proportion in the diet as it does in the environment.

## RESULTS

Darters captured in December (N = 10) ranged in standard length (SL) from 35 to 52 mm ( $\bar{x}$ = 43.4 mm) and had a sex ratio of 1:1. February collections consisted of 1 male and 9 females, with SL ranges of 39 to 52 mm ( $\bar{x}$ = 47.5 mm). All darters examined had at least one food item in their stomachs, averaging 5.3 items per individual in December and 12.3 items per individual in February. Analysis of diversity indices for stomach samples indicated that a minimum of eight stomachs were needed to represent dietary diversity for each collection. The overall diversity was relatively low (H = 1.247 and evenness = 0.775 in December; and H = 0.755 and evenness = 0.469 in February).

The diet of *E. spectabile* in both collections consisted predominately of chironomid larvae and isopod crustacea (Table 1). Chironomid larvae contributed less than half of the total diet in December, yet accounted for 78.9% of the total diet in February. The average number of chironomid larvae per individual increased from 1.9 in December to 9.7 in February. *Caecidotea* represented 43.5% of the diet in December, declining to 12.2% by February. The average number of isopods per individual decreased from 2.4 in December to 1.5 in February. Trichopteran larvae and amphipods were minor components in the diet, while copepods and oligochaetes were incidental in the diet. The average number of trichopteran larvae and amphipods per stomach did not appreciably change between the two collections.

Overall prey density increased by a factor of 10 between the two collections (Table 2). All major prey item populations experienced this increase along with subtle changes in the proportional representation within the resource base. The benthic community of Road Brook was dominated by the four major taxa comprising the diet (Table 2). Chironomid larvae made up about 50% of the total available food items in each collection, while *Caecidotea* declined in relative proportion from 46% in December to 36% in February. *Lepidostoma* and *Gammarus* were minor components of the resource base. Other taxa collected from the stream but not found in the stomach of *E. spectabile* included Tipulidae, Ceratopogonidae, Tabanidae, and Libellulidae. These taxa were listed as minor components of the diet of *E. spectabile* in other studies (Martin, 1984; Small, 1975). The simplicity of the diet reflected the nature and structure of the resource base in Road Brook. First order streams generally have less diversity and productivity in invertebrate fauna than higher order streams (Kuehne, 1962; Small, 1975).

Electivity indices for three of the four major taxa in the diet shifted between December and February (Table 1). *Caecidotea,* the major food item in December, was preyed upon at approximately the same frequency as it occurred in the environment (E = 0.02)but was later selected against (E = -0.49). Chironomid larvae were the only taxa selected against in December (E = -0.10) but were positively selected for in February (E = 0.2). The taxon with the highest positive electivity index was *Lepidostoma* in December (E = 0.61), but this taxon was later avoided (E = -0.14). *Gammarus* was the only taxon in the diet that had a positive electivity index during both months (E = 0.23 in December and E = 0.04 in February). Oligochaete worms were present in the diet at the same frequency as the taxon was in the environment during February (E = 0.04). No electivity index could be calculated for copepoda due to its absence in benthic samples.

## DISCUSSION

This diet is consistent with the diet of darters in general (Page, 1983) but differs in the number of taxa reported comprising the diet of the orangethroat darter in other studies. Martin (1984) found that chironomid larvae were the major food item of a population of *E. spectabile* in central Indiana, with ephemeropteran naiads, plecopteran nymphs, simuliid larvae, and isopod crustacea being minor constituents. Tendipedidae (= Chironomidae) larvae and the isopod *Lirceus* were the major components of the diet in a second order Kentucky stream, with ephemeropteran and odonate naiads, trichopteran and coleopteran larvae, amphipod crustacea, annelid worms, and gastropods as food items of minor importance (Small, 1975).

Shifts in the electivity for specific food items suggests a relationship between foraging strategy and prey density. Chironomidae was the major component per item of the benthos but was selected against in December when prey densities were low. The tube dwelling dipterans may not be as easily obtained as *Caecidotea* and may have been passed over in favor of the cursorial isopods at this time. Isopod crustacea are low in nutritional value relative to chironomid larvae (Cummins and Wuycheck, 1971) and were the major component of the diet only when food item availability was low. Isopods have been found to be important in the winter and spring diets of the mud darter (*Etheostoma asprigene*) and the slough darter (*E. gracile*) (Cummings, *et al.,* 1984; Strange, 1992), although this food item is normally associated with the diet of larger darter species (Page, 1983). The importance of such lower quality food in the winter diet of smaller darters may be a function of obtainability and lower metabolic demands during the coldest months.

Orangethroat and rainbow (*E. caeruleum*) darters have been observed to increase foraging activities in habitats with low invertebrate densities (Vogt and Coon, 1990). Although morphology largely determines the diet of darters (Page and Swofford, 1984), the electivity of the orangethroat darter in this study for specific taxa changed concurrently with a general increase in prey density, while proportional representation within the resource base remained relatively stable. If increased search time is the result of decreased prey availability, then the optimally foraging predator would be expected to maximize its foraging efficiency by broadening dietary selection (Pianka, 1983). When food item abundance is low, *E. spectabile* may be an opportunistic forager, preying upon whatever it encounters. At higher prey densities, the darter may be more selective, avoiding or ignoring those items of low nutritive value in favor of more preferred food items. This is consistent with predictions based on optimal foraging models: dietary specialization is favored when habitat production increases and is discouraged when production decreases (Ricklefs, 1979). Although the sample size in this study was small, these results suggest that future investigations of darter food habits should consider prey density (both specific and overall) as a factor determining food item selection.

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## LITERATURE CITED

Burr, B.M. and M.L. Warren. 1986. A distributional atlas of Kentucky fishes. Kentucky Natur. Pres. Comm. Sci. Tech. Ser. 4, Frankfort, Kentucky, 398 pp.

Cummings, K.S., J.M. Grady, and B.M. Burr. 1984. The life history of the mud darter, *Etheostoma asprigene,* in Lake Creek, Illinois. Illinois Natur. Hist. Surv. Biol. Notes 122, 16 pp.

_________ and J.C. Wuycheck. 1971. Caloric equivalents for investigations in ecological energetics. Mitt. Int. Verein. Limnol. 18, 158 pp.

Fisher, W.L. and W.D. Pearson. 1987. Patterns of resource utilization among four species of darters in three Kentucky streams. *In:* W.J. Matthews and D.C. Heins (Eds.), *Community and Evolutionary Ecology of North American Stream Fishes,* pp. 69-76, Univ. Oklahoma Press, Norman, Oklahoma, 310 pp.

Grannan, L. and J. Lodato. 1986. Status and distribution of darters in southwestern Indiana. Indiana Dep.

Natur. Res. Nongame Wildlife Small Grant Prog. Rep., Indianapolis, Indiana, 22 pp.

Hansen, M.J., S.P. Gloss, and B.L. Peckarsky. 1986. Predator species richness and prey population variability: Effects on diets of benthic stream fishes. Amer. Midl. Natur. 115: 63-72.

Hlohowskij, I. and A.M. White. 1983. Food resource partitioning and selectivity by the greenside, rainbow and fantail darters (Pisces: Percidae). Ohio J. Sci. 83: 201-208.

Hurtubia, J. 1973. Trophic diversity measurement in sympatric predatory species. Ecology 54: 885-891.

Ivlev, V.S. 1961. Experimental ecology of feeding of fishes.Yale Univ. Press, New Haven, Connecticut, 302 pp.

Kozel, T.R., G.K. Weddle, K.L. Welborn, J.T. Daily, D.C. Daily, and M.W. Denner. 1981. A fish faunal survey of Posey County, Indiana. Proc. Indiana Acad. Sci. 90: 446-453.

Kuehne, R.A. 1962. A classification of streams illustrated by fish distribution in an eastern Kentucky creek. Ecology 43: 608-614.

Martin, F.D. 1984. Diets of four sympatric species of *Etheostoma* (Pisces:Percidae) from southern Indiana: Interspecific and intraspecific multiple comparisons. Env. Biol. Fish. 11: 113-120.

Merritt, R.W. and K.W. Cummins. 1984. An introduction to the aquatic insects of North America. Kendall/Hunt Publ., Dubuque, Iowa, 722 pp.

Miller, G.L. 1983. Trophic resource allocation between *Percina sciera* and *P. couachitae* in the Tombigbee River, Mississippi. Amer. Midl. Natur. 110: 299-313.

Nelson, J.S. and S.D. Gerking. 1968. Annotated key to the fishes of Indiana. Indiana Aquatic Res. Unit, Bloomington, Indiana, 84 pp.

Page, L.M. 1983. Handbook of darters. T.F.H. Publications , Inc., Neptune City, New Jersey, 271 pp.

_________ and D.L. Swofford. 1984. Morphologic correlates of ecological specializations in darters. Environ. Biol. Fishes 11: 139-159.

Pennak, R.W. 1989. Fresh water invertebrates of the United States. Wiley and Sons, New York, New York, 628 pp.

Pianka, E.R. 1983. Evolutionary ecology. Harper and Row Publ., New York, New York, 416 pp.

Ricklefs, R.E. 1979. Ecology. Chiron Press, New York, New York, 966 pp.

Small, J.W. 1975. Energy dynamics of benthic fishes in a small Kentucky stream. Ecology 56: 827-840.

Strange, R.M. 1991. Dietary preferences of the slough darter *Etheostoma gracile,* in Cypress Slough, southwestern Indiana. Proc. Indiana Acad. Sci. 100: 161-165.

Vogt, G.F. and T.G. Coon. 1990. A comparison of the foraging behavior of two darter (*Etheostoma*) species. Copeia 1990: 41-49.

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# THE MANUBRIUM-STERNUM BRIDGE IN SONGBIRDS (OSCINES)

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ABSTRACT. The manubrium-sternum bridge was first described by Shufeldt (1888). In this study, all the Oscine families, most of the subfamilies, and nearly all the species in Parulidae and Thraupinae were surveyed. The structure is well-developed in at least some species within Picathartidae, Sylviidae, Maluridae, Monarchidae, Remizidae, Parulidae, Emberizinae, Cardinalinae, Thraupinae, Tersininae, Fringillinae, Carduelinae, and Bubalornithinae. From the erratic systematic distribution of the structure, the manubrium-sternum bridge apparently does not supply phylogenetic information at the family level, although it does at the generic level in some cases.

## INTRODUCTION

A bony bridge between the dorsal surface of the manubrium and the coracoid ridge of the sternum was first described by Shufeldt (1888) in the tanager *Piranga ludoviciana.* Clark (1913) noted the structure in *Rhodinocichla rosea* as well as in *Piranga olivacea* and suggested that it was characteristic of tanagers in contrast to other songbirds. Moreno (1984) described a bridge, which she called the spina interna, in 3 species of *Fringilla* and 4 species of *Cisticola.* Morony (1985) described the structure in the tanager *Sericossypha albocristata* as the processus manubrii without reference to the earlier literature. The manubrium-sternum bridge is more generally distributed among the Oscines than earlier authors indicated, but it is not consistent within most species or higher group taxa. To study its distribution, 1375 skeletons representing 331 genera and 628 species were examined (Table 1).

Table 1 and the results presented below follow the classification in Peters (1960-1986) with five exceptions. The classification of the Old World insect eaters follows the more recent Volume 11 rather than earlier volumes. *Coereba* and *Conirostrum* are removed from Parulidae to a separate subfamily Coerebinae of Emberizidae, following the American Ornithologists' Union's check-list (1983). *Zeledonia* is removed from Turdidae to Parulidae, following Sibley (1968) and the American Ornithologists' Union (1983). *Microligea, Xenoligea,* and *Granatellus* are removed from Parulidae to Thraupinae, following Webster (1989, in press). A few species and genera described as new since the appropriate volume of Peters was published are added, if their skeletons were examined.

## RESULTS

In many tanagers, e.g., *Heterospingus xanthopygius,* the manubrium-sternum bridge is a stout, bony, medial rod extending from the midpoint of the coracoid ridge (= labrum dorsale) of the sternum to the dorsal midpoint of the manubrium (= rostrum sterni) one-third of its length out. In a few specimens of seed eaters, e.g., *Rhodothraupis celaeno* (Emberizidae, Cardinalinae), the bridge is even larger and longer (Figure 1, Rhodot) than in any tanager. The *Rhodothraupis* scale of bridge was characterized as "very large," and the *Heterospingus* scale of bridge was characterized as "large." In many tanagers, e.g., *Tachyphonus luctuosus* (Figure 1, Tach), the bridge is as long as in *Heterospingus,*

Table 1. The distribution of skeletons examined in this study.

| Taxon | Number of Genera | Number of Species | Number of Specimens |
|---|---|---|---|
| Alaudidae | 1 | 1 | 2 |
| Hirundinidae | 3 | 3 | 3 |
| Motacillidae | 2 | 2 | 5 |
| Campephagidae | 1 | 1 | 1 |
| Pycnonotidae | 1 | 1 | 1 |
| Irenidae | 3 | 3 | 3 |
| Laniidae | 2 | 2 | 2 |
| Vangidae | 2 | 2 | 2 |
| Bombycillidae | 3 | 3 | 5 |
| Dulidae | 1 | 1 | 1 |
| Cinclidae | 1 | 2 | 2 |
| Troglodytidae | 3 | 3 | 5 |
| Mimidae | 4 | 4 | 19 |
| Prunellidae | 1 | 2 | 2 |
| Turdidae | 8 | 10 | 9 |
| Orthonychidae | 1 | 1 | 1 |
| Timaliidae | 4 | 4 | 4 |
| Panuridae | 1 | 1 | 1 |
| Picathartidae | 1 | 1 | 1 |
| Polioptilidae | 3 | 3 | 4 |
| Sylviidae | 24 | 38 | 52 |

| Taxon | Number of Genera | Number of Species | Number of Specimens |
|---|---|---|---|
| Muscicapidae | 4 | 8 | 12 |
| Platysteiridae | 2 | 2 | 2 |
| Maluridae | 1 | 3 | 3 |
| Acanthizidae | 5 | 7 | 7 |
| Monarchidae | 10 | 12 | 13 |
| Eopsaltridae | 3 | 4 | 5 |
| Pachycephalidae | 2 | 2 | 2 |
| Aegithalidae | 2 | 2 | 2 |
| Remizidae | 2 | 2 | 3 |
| Paridae | 1 | 1 | 5 |
| Sittidae | 2 | 3 | 4 |
| Certhiidae | 2 | 6 | 18 |
| Rhabdornithidae | 1 | 1 | 1 |
| Climacteridae | 1 | 1 | 1 |
| Dicaeidae | 2 | 2 | 2 |
| Nectariniidae | 1 | 1 | 1 |
| Zosteropidae | 1 | 1 | 4 |
| Meliphagidae | 5 | 5 | 9 |
| Vireonidae | 4 | 7 | 15 |
| Parulidae | 22* | 97 | 326 |
| Emberizinae | 49 | 75 | 142 |
| Catamblyrhynchinae | 1 | 1 | 2 |

| Taxon | Number of Genera | Number of Species | Number of Specimens |
|---|---|---|---|
| Cardinalinae | 7 | 11 | 33 |
| Thraupinae | 58[**] | 193 | 446 |
| Tersininae | 1 | 1 | 3 |
| Coerebinae | 2 | 6 | 17 |
| Drepanididae | 3 | 3 | 3 |
| Icteridae | 19 | 26 | 58 |
| Fringillidae | 9 | 15 | 48 |
| Estrildidae | 10 | 11 | 11 |
| Ploceidae | 13 | 16 | 31 |
| Sturnidae | 3 | 3 | 9 |
| Oriolidae | 1 | 1 | 1 |
| Dicruridae | 1 | 1 | 1 |
| Callaeidae | 1 | 1 | 1 |
| Grallinidae | 1 | 1 | 1 |
| Artamidae | 1 | 1 | 1 |
| Cracticidae | 1 | 1 | 1 |
| Ptilonorhynchidae | 2 | 2 | 3 |
| Paradisaeidae | 1 | 1 | 1 |
| Corvidae | 4 | 5 | 8 |

[*] All except *Leucopeza.*

[**] All except *Orchesticus, Compsothraupis, Calyptophilus,* and *Cyanicterus.*

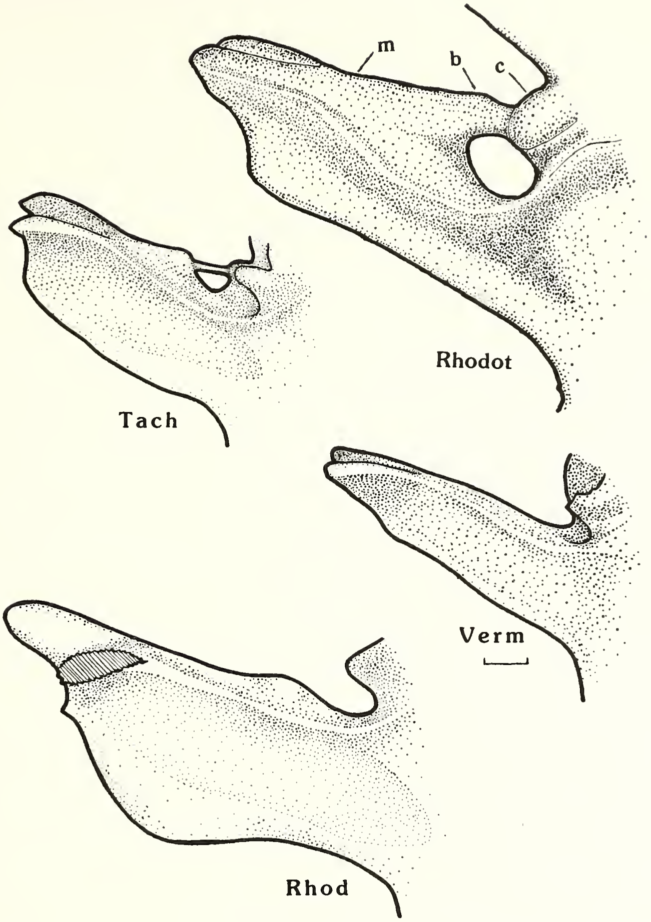

Figure 1. All figures are left lateral views of the rostral end of the sternum drawn with the aid of a camera lucida to the same scale. The scale line, drawn under "Verm[ivora]," is 1 mm. Top left: *Tachyphonus luctuosus,* with a small bridge. Top right: *Rhodothraupis celaeno,* with a very large bridge. Lower left: *Rhodinocichla rosea,* showing a minute bridge with the ligamentous part of the span missing; the left rostral point of the manubrium has been deleted. Lower right: *Vermivora gutturalis,* with no bridge. Labels are: b, manubrium-sternum bridge; c, coracoid ridge; and m, manubrium.

but it is more slender and sometimes the middle quarter of the span is ligamentous. Such a bridge was characterized as "small." In quite a few tanagers and buntings, e.g., *Tangara nigrocincta,* the bridge was characterized as "minute"; in this case, the middle three-fourths of the span is ligamentous (missing in many skeletal preparations), and only the termini are bony (Figure 1, Rhod). When the bridge is distinctly shorter than one-third the length of the manubrium, as it often is in non-tanagers, it is described it as "short."

Table 2. Songbird familes and subfamilies in which a manubrium-sternum bridge was observed. In an additional 44 families, no bridge was present; they are listed in Table 1.

| Taxon | Bridge occurrence | Bridge type if present |
|---|---|---|
| Irenidae | Occasional | Minute |
| Mimidae | Occasional | Minute |
| Picathartidae | Present | Small |
| Sylviidae | Frequent | Ridge; large, small or minute |
| Maluridae | Frequent | Large |
| Monarchidae | Occasional | Ridge; large |
| Remizidae | Frequent | Ridge; large |
| Meliphagidae | Occasional | Minute |
| Parulidae | Rare | Small or minute |
| Emberizidae, Emberizinae | Erratic | Large, small, or minute; rarely a ridge |
| Emberizidae, Cardinalinae | Erratic | Very large, small, or minute |
| Emberizidae, Thraupinae | Frequent | Large, small, or minute |
| Emberizidae, Tersininae | Present | Large, small, or minute |
| Emberizidae, Coerebinae | Occasional | Minute |
| Icteridae | Rare | Minute |
| Fringillidae,Fringillinae | Present | Very large, large, or minute |
| Fringillidae, Carduelinae | Rare | Small or minute |
| Ploceidae,Bubalornithinae | Present | Very large |
| Ploceidae, Passerinae | Occasional | Minute |
| Corvidae | Occasional | Minute |

The bridge was missing in all the specimens examined from those 44 families and all those genera not discussed below. Table 2 summarizes this data.

In Irenidae, a minute bridge was present in *Irena puella* but not in *Chloropis aurifrons* or *Aegithina typhia.* In Mimidae, a minute bridge was present in 1 of the 5 specimens of *Toxostoma rufa.* In Picathartidae, the single specimen of *Picathartes oreas* had a small, short bridge. In Sylviidae, there was great variation, but the structure, when present, was really a ridge rather than a bridge, because there was a thin, median keel of attachment to the manubrium from the dorsal rod. The ridge was absent in *Bradypterus, Melocichla, Megalurus, Hippolais, Chloropeta similis, Urolais, Apalis, Phyllolais, Eremomela pusilla, Hyliota, Phylloscopus,* and *Sylvia.* A large, short ridge was present in *Bathmocercus cerviniventris, Nesillas typica, Cisticola chubbi, C. chiniana, C. natalensis, Camaroptera brachyura, Eremomela scotops, Sylvietta brachyura,* and *Hypergerus lepidus.* A small, short ridge was present in *Acrocephalus schoenobaenus, Chloropeta natalensis, Orthotomus atrogularis,* and *Macrosphenus concolor.* Of 2 specimens of *Acrocephalus scirpaceus,* one had a small, short ridge, and the other had a minute, short ridge. Of 2 specimens of *Prinia subflava,* one had a large, short ridge, and the other had a small, short ridge. In the single specimen of *Prinia leucopogon,* the apparent corresponding structure was abbreviated into an almost vertical column supporting the coracoid ridge. In *Regulus,* the ridge was absent in 5 specimens each of *R. satrapus* and *R. calendula,* but in the one *R. ignicapillus* specimen, a column appeared caudally as in *Prinia leucopogon.*

In Maluridae, there was no bridge in *Malurus alboscapulatus,* but in a single specimen each of *M. cyaneus* and *M. coronatus,* there was a large, short bridge. In Monarchidae, there was a large, short ridge (as in Sylviidae) in the single specimen of *Philentoma pyrrhopterum* examined, and in the one *Terpsiphone viridus* specimen examined, there was a caudal, almost vertical column as in *Prinia leucopogon.*

In Remizidae, there was no bridge in *Auriparus,* but in *Remiz,* a large, short ridge (as in Sylviidae) was present. In Meliphagidae, there was no bridge in 4 genera, but a single specimen of *Promerops* had a minute bridge. In Parulidae, the bridge was absent in 17 genera but present in at least one specimen in each of 5 other genera. Within *Dendroica* (all 27 species examined), the bridge was absent in 22 species. It was small and short in all 4 specimens of *D. pharetra*; minute and short in 2 of 7 specimens of *D. plumbea* (absent in 5); minute and short in 1 of 3 specimens of *D. pinus* (absent in 2); minute and short in 1 of 5 specimens of *D. graciae* (absent in 4); and minute and short in 1 of 3 specimens of *D. adelaidae.* The bridge was small and short in both specimens of *Catharopeza bishopi.* Within *Seiurus* (all 3 species examined), the bridge was absent in all 6 specimens of 2 species and in 2 of 3 specimens of *S. noveboracensis,* but in one Ovenbird, there was a short, minute bridge. Within *Geothlypis* (12 species examined — all except *G. beldingi*), the bridge was absent in 9 species (including the 4 usually referred to *Oporornis*). The bridge was small and short in the single specimen of *G. nelsoni*; minute and short in 1 of 12 specimens of *G. trichas* (absent in 11); and small and short in 1 of 2 specimens of *G. speciosa* (absent in one). Within *Basileuterus,* the bridge was absent in 15 species but short and minute in both specimens of *B. signatus.*

In Emberizinae (Emberizidae), the bridge was missing in 37 genera but was present to some degree in 12 genera. In *Ammodramus,* there was a large, short bridge in one specimen of *A. maritimus* and a minute, short bridge in the other specimen; there was a minute, short bridge in 1 of the 2 specimens of *A. sandwichensis*; and the bridge was absent in both specimens of *A. savannarum.* In *Aimophila,* the bridge was absent in 18 specimens of 8 species, but minute and short in 1 of 2 specimens of *A. aestivalis.* In *Oriturus, Sporophila,* and *Pselliophorus,* there was a condition as in *Prinia leucopogon* (see above) — a large vertical column or post extending from the caudal end of the manubrium to the dorsal midpoint of the coracoid ridge. In *Melanospiza,* there was a small, short bridge in one specimen but none in another. In *Piezorhina* and *Geospiza,* there was a small, short bridge. Of the 4 specimens of *Certhidea,* one had a large, short ridge (i.e., with a keel of attachment to the manbrium), one a small, short bridge, one a minute, short bridge, and one no bridge. In *Arremonops,* the single specimen had a small, short ridge (i.e., with a keel of attachment to the manubrium). In *Saltatricula, Coryphospingus,* and *Paroaria,* there was a minute bridge in each case.

In Cardinalinae, the bridge was absent in *Spiza, Pheucticus, Saltator,* and *Passerina.* In *Cardinalis cardinalis,* there was a minute bridge in 6 but none in 4 other specimens. In *C. sinuatus,* the single specimen had a small bridge. In *Caryothraustes,* all 3 specimens had a minute bridge. In *Rhodothraupis,* the single specimen had a very large bridge.

In Thraupinae (Emberizidae), the bridge was erratic in occurrence. In 28 genera, the bridge was absent, but in 30 genera, it was present in at least some of the specimens. In *Heterospingus,* it was large in the 2 specimens examined. In *Chlorophanes,* it was large in 2, small in 2, and minute in one. In *Habia,* 10 specimens (including 4 species; all except *H. cristata*) all had the bridge, but it varied from large to minute. In *Cyanerpes,* 11 specimens (including all 4 species) all had the bridge, and it was either small or minute. In *Conothraupis speculigera,* both specimens had a minute bridge. In *Sericossypha albocristata,* one (the specimen discussed by Morony, 1985) had a large bridge, but one had none. In *Hemithraupis* (both species), all 5 specimens of *H. guira* had the bridge, though it varied from large to minute; 4 specimens of *H. flavicollis* included 2 with a small bridge, one with a minute bridge, and one with none. In *Nephelornis oneilli,* one had a large bridge, but 4 had none. In *Rhodinocichla rosea,* 2 of the 7 specimens had a small bridge, 4 had a minute bridge, and one had none. In *Nemosia pileata,* the bridge was small in one specimen but missing in 3. In *Tachyphonus* (all 8 species examined), the bridge was either small or minute in 11 specimens (total for *T. rufiventer, T. luctuosus, T. coronatus,* and *T. phoeniceus*) but absent in 6 specimens (total for *T. cristatus, T. surinamus,* and *T. delatrii*). In *Piranga* (8 of the 9 species examined), the bridge was absent in all 4 specimens of *P. leucoptera,* both specimens of *P. erythrocephala,* and 2 of 9 specimens of *P. rubra.* It was present but varying from large to small to minute in all 3 specimens of *P. bidentata*, both specimens of *P. flava,* 7 of the 9 specimens of *P. rubra,* all 3 specimens of *P. roseogularis,* all 5 specimens of *P. olivacea,* and all 5 specimens of *P. ludovicianus.* In *Xenodacnis parina,* one specimen had a small, short bridge, but 2 others had none. In the genera *Schistochlamys, Lamprospiza, Nesospingues, Hemispingus, Phoenicophilus, Microligea, Chlorothraupis, Eucometis, Trichothraupis, Rhamphocelis, Iridosornis, Delothraupis, Chlorochrysa, Tangara, Oreomanes, Diglossa,* and *Euneornis,* the bridge was usually missing, but in a few scattered specimens, it was present but minute.

In Tersininae (Emberizidae), the bridge in 3 specimens of *Tersina viridis* varied in size from large to minute. In Coerebinae, the bridge was minute in 2 of 7 specimens of *Coereba flaveola* but absent in 10 specimens of 5 species of *Conirostrum* and the other 5 *Coereba.* In Icteridae, the bridge was absent in all genera except in 1 of 2 specimens each of 3 species of *Cacicus,* in which it was minute.

In Fringillinae (Fringillidae), the bridge was always present; it was very large or large in 10 specimens of *Fringilla coelebs* and in one specimen of *F. teydea,* but it was minute in 3 specimens of *F. montifringilla* (also described by Moreno, 1984). In Carduelinae, it was absent except in 1 of 3 specimens of *Serinus,* where it was small, and in 1 of 2 specimens of *Carduelis flammea,* where it was minute. In Ploceidae, the bridge was very large in one specimen each of *Bubalornis* and *Dinemellia* but absent in *Passer montanus, Petronia, Montifringilla, Sporopipes, Amblyospiza, Ploceus, Malimbus, Quelea, Foudia, Euplectes,* and *Vidua paradisaea.* In *Passer domesticus,* it was minute in 7 specimens and absent in 2; in *Vidua chalybeata,* it was minute in a single specimen. In Corvidae, a minute bridge was present in 1 of 3 specimens of *Cyanocitta cristata.*

## DISCUSSION

These data constitute a single character study (*sensu* Bock, 1960), especially when combined with the data provided by Moreno (1984). The erratic occurrence of the manubrium-sternum bridge leads to the conclusion that its presence or absence tells us little or nothing about the evolution of major passerine groups (= families). On the other hand, within those groups (Parulidae and Thraupinae) which were studied rather completely, the pattern of occurrence and size of the structure suggests some possible generic and specific relationships. For example, among the New World warblers, the bridge is generally absent or minute and rare. But in *Catharopeza bishopi* of St. Vincent and *Dendroica pharetra* of Jamaica, the bridge was present and small in all specimens examined. *Dendroica plumbea* from the Lesser Antilles and *D. adelaidae* from St. Lucia were among the very few other parulids in which a minute bridge occurred in even a minority of specimens. A single specimen of *D. angelae* from Puerto Rico (borrowed from Louisiana State University) lacked the bridge. Kepler and Parkes (1972) suggested that *Catharopeza bishopi, D. pharetra, D. plumbea,* and *D. angelae* constituted a West Indian superspecies on the basis of distribution and external anatomical features. The distribution and size of the manubrium-sternum bridge support Keppler and Parkes' suggestion of relationships among *C. bishopi, D. pharetra,* and *D. plumbea,* but neither support nor deny the relationship of these species to *D. angelae.* Other systematic relationships are suggested within families wherein sampling was inadequate. Within Sylviidae, the distribution and size of the ridge suggest a very different sequence of genera than that adopted by Mayr and Cottrell (Peters, 1986, Vol. 11). The peculiar "ridge, not bridge" structure was observed almost exclusively in Sylviidae and Monarchidae, which suggests phylogenetic relationship, yet was uncomfortably erratic in occurrence. Within Emberizinae and Cardinalinae, the erratic distribution of the bridge calls for further study. Within Fringillidae, the consistent presence of the bridge in *Fringilla,* but not the other genera, lends weight to the separation of a subfamily Fringillinae from Carduelinae (cf. Moreno, 1984). Within Ploceidae, the very large bridge in *Bubalornis* and *Dinemellia,* along with its absence or minute presence in other genera, lends weight to the separation of a subfamily Bubalornithinae.

The function of the manubrium-sternum bridge is unknown, although it must strengthen the manubrium dorsally. Perhaps the bridge provides extra bracing in species with unusually far rostral extension of the supracoracoideus muscle.

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## LITERATURE CITED

American Ornithologists' Union. 1983. Check-list of North American birds. American Ornithologists' Union, Lawrence, Kansas, 877 pp.

Bock, W.J. 1960. The palatine process of the premaxilla in the Passeres. Bull. Mus. Comp. Zool. 122: 361-488.

Clark, H.L. 1913. Notes on the Panama thrush-warbler. Auk 30: 11-15.

Kepler, C.B. and K.C. Parkes. 1972. A new species of warbler (Parulidae) from Porto Rico. Auk 89: 1-18.

Moreno, E. 1984. Una variacion del patron general del sternum de los Passeriformes. Ardeola 30: 109-113.

Morony, J.J., Jr. 1985. Systematic relations of *Sericossypha albocristata* (Thraupinae). *In:* P.A. Buckley, M.S. Foster, E.S. Morton, R.S. Ridgely, and F.G. Buckley (Eds.), *Neotropical Ornithology,* pp. 383-389, Ornithological Monog. 36: 1-1041.

Peters, J.L. and others. 1960-1986. Check-list of birds of the world, Vols. 9-15. Mus. Comp. Zool. Cambridge, 3332 pp.

Shufeldt, R.W. 1888. The osteology of *Habia melanocephala,* with comparative notes upon the skeletons of certain other conirostral birds and of tanagers. Auk 5: 438-444.

Sibley, C.G. 1968. The relationships of the wren-thrush, *Zeledonia coronata* Ridgway. Postilla 125: 1-12.

Webster, J.D. 1989 ms. Skeletons and the genera of warblers.

_______. In press. Skeletons and the genera of tanagers. Proc. Indiana Acad. Sci. 98.

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# MOVEMENTS OF FEMALE WHITE-TAILED DEER IN SOUTHERN INDIANA

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ABSTRACT: Movements and habitat use by female white-tailed deer (*Odocoileus virginianus*) in southern Indiana during 1979-1981 revealed that home ranges averaged 70 ± 4 ha (±SE) in spring, 50 ± 5 ha in summer, and 55 ± 13 ha in autumn. Fidelity to seasonal and lifetime home ranges appeared to be high. Most deer selected bottomlands over uplands in summer. During this season, does were most active near dusk (from 1800 - 2200 h) and traveled an average of 1,890 ± 67 m per day. Deer infrequently left their home ranges temporarily to make exploratory trips and to flee from disturbances; permanent dispersals by does were not recorded.

## INTRODUCTION

Despite the importance of white-tailed deer as a game animal, few published accounts describe the movements and habitat use of this species in the forested, hilly regions of the central States of the Mississippi River Basin. Prior investigations in Missouri (Progulske and Baskett, 1958), southern Indiana (Hamilton, 1962), and Illinois (Hawkins, *et al.,* 1971) examined limited aspects of deer movements without the benefits of radio-telemetry. During an investigation of the movements and use patterns of white-tailed deer visiting mineral licks in southern Indiana (Wiles and Weeks, 1986), data were gathered for female deer on 1) home range, 2) habitat use, 3) activity patterns, and 4) movements outside normal home ranges.

## STUDY AREA

The study was conducted on a 3,200-ha portion of the Crane Naval Weapons Support Center (NWSCC) in Martin County in south-central Indiana (38°49,N, 86°50,W). Ridges running through the area are moderately-to-steeply (15%-35%) sloped and reach elevations of 250 m. Flat alluvial bottomlands occur along streams at elevations of 150 m. Kirkpatrick, *et al.* (1976) described the plant communities at NWSCC. Oak-hickory (*Quercus* and *Carya* spp.) forest is the most common habitat in the study area and occupies most hillsides and ridges. Old fields on abandoned farmlands are present within tracts of upland forest and are composed primarily of broomsedge (*Andropogon* spp.) and invading woody species. In bottomlands, where flooding periodically occurs, hardwood forests with sycamore (*Plantanus occidentalis*), river birch (*Betula nigra*), and pin oak (*Q. palustris*) are interspersed with brushy fields.

## METHODS

Field work was carried out from February 1979 to December 1980 and from

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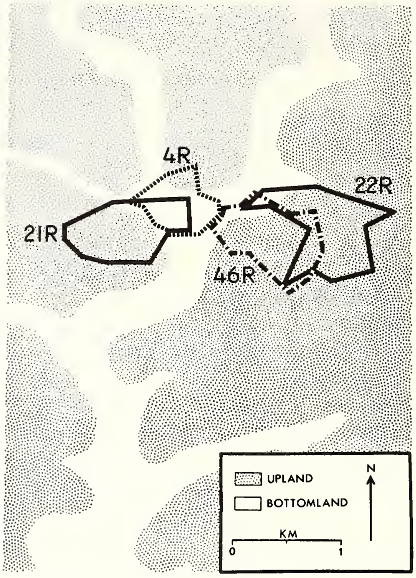

Figure 1. Summer home ranges of four radio-collared females at NWSCC, Indiana, in 1980. Does 4R and 46R were adults, and Does 21R and 22R were yearlings.

November to December 1981. Seasons were designated as: spring (1 March to 15 May, the initial date of fawning; Kirkpatrick, *et al.,* 1976); summer (16 May to 31 August); autumn (1 September, the time when mast crops became available for consumption, to 15 December); and winter (16 December to 29 February).

Although 48 deer were immobilized and fitted with numbered neck collars or radio-transmitters, only 6 does were radio-tracked for sufficient time to allow home range and seasonal movement assessment. Ages were determined by tooth wear and replacement. The six animals with radio collars were located either visually or by ground triangulation with a portable 3-element yagi antenna. Most bearings were taken at locations 250-750 m from the animal's position and were plotted on topographic maps (1:24,000) with tracking grids. Generally, radio locations fell within 75 m of the animal's actual location as determined visually by observers. "Fixes" were taken at 2-hour intervals at all times of day but particularly from 1800 to 0100 h, the period when deer visit mineral licks most frequently. In addition, each deer was tracked for two or three 24-hour periods in each summer month.

The modified minimum area method (Harvey and Barbour, 1965) was used to determine home ranges, considering outlying points as not being part of the normal home range and eliminating them from data analysis. Range boundaries contained 90%-100% of the fixes recorded for an animal. Areas were plotted on maps, and their sizes were measured with a polar planimeter. The minimum total distance moved per day was defined as the sum of the straight-line distances between sequential locations of an indi-

Table 1. Seasonal home range sizes for six radio-collared female white-tailed deer at NWSCC, 1979-1980.

| Deer Number | Age (yrs.) | Age Home Range Area[a] (ha) | | |
|---|---|---|---|---|
| | | Spring | Summer | Autumn |
| 4R | adult | | 28 (154) | |
| 21R | 1 | | 47 (217) | |
| 22R | 1 | | 53 (140) | |
| 32R | 2 | 74 (84) | 68 (181) | 68 (60) |
| | 3 | 51 (229) | | |
| 35R | 10 | 66 (76) | 48 (196) | 42 (61) |
| 46R | 2 | 56 (152) | | |
| Average | | 70 | 50 | 55 |

[a] Number in parentheses represents the number of locations used to determine each home range.

vidual deer during a 24-hour period (Laundre, *et al.,* 1987).

Resightings made incidental to routine research travel of collared but non-radioed deer along roadsides provided additional data on home range and movement patterns. Because these locations were fewer in number and restricted to roadsides, the information they supplied about the ranges of nonradioed animals was not included for statistical analysis. Marked animals killed by hunters (n = 20) or in highway accidents (n = 2) supplied a limited number of locations.

Habitat use was determined from radio-locations of transmittered deer. Each deer was captured within 500 m of an upland-bottomland interface; thus, each animal had a clear choice in the habitat that it used. Although home ranges of these deer overlapped to some degree, all were members of different social groups, and the observations are independent. Habitat types were delineated for an 880-ha area encompassing the home ranges of these animals, with uplands comprising 76.3% of this area and bottomlands the remaining 23.7%; percentages of both habitat types within each home range were compared with these values. Because deer were strongly attracted to mineral licks that occur only in bottomlands, locations made within 1 hour of known visits to licks were deleted from habitat use analysis to avoid possible bias associated with lick use.

## RESULTS AND DISCUSSION

**Home range sizes.** Home ranges of does averaged 70 ± 4 ha (±SE) in spring (n =

Table 2. Monthly variation in home range sizes for six radio- collared female white-tailed deer during the summer at NWSCC, 1979-1980.[a]

| Deer Number | Age (yrs.) | Home Range Area (ha)<br>Mid-May To June | July | August |
|---|---|---|---|---|
| 4R | adult | 27 | | |
| 21R | 1 | 36 | 22 | 21 |
| 22R | 1 | | 33 | 33 |
| 32R | 2 | 45 | 37 | |
| | 3 | 18 | 33 | 22 |
| 35R | 10 | 37 | 22 | |
| 46R | 2 | | 44 | 40 |
| Average | | 33 | 34 | 29 |

[a] Number of locations per home range varied from 66 to 110 locations/month ($\bar{x} = 78.3$ locations/month).

2), 50 ± 5 ha in summer (n = 7) (Figure 1), and 55 ± 13 ha in autumn (n = 2) (Table 1). Ranges varied in size from 28 to 74 ha during these seasons. These home ranges are comparable in size to those reported elsewhere for nonmigratory female white-tailed deer (Progulske and Baskett, 1958; Michael, 1965; Marchington and Jeter, 1966; Byford, 1970; Bartush and Lewis, 1978; Larson, *et al.,* 1978; Inglis, *et al.,* 1979; Ivey and Causey, 1984; Holzenbein and Schwede, 1989; Beier and McCullough, 1990).

Comparisons of summer home ranges on a monthly basis indicated no restrictions in adult doe movements during the last half of May and June after fawning (Table 2). No significant difference appeared in range size (1-way ANOVA, $P > 0.70$) among the mid-May to June, July, and August periods. Range sizes averaged 34 ± 3 ha for individual summer months. Ranges of yearling does without fawns were slightly longer and narrower but otherwise similar to those of adult females (Table 2), a further indication that caring for fawns had little effect on adult female home ranges. In contrast, some authors have reported reductions in home range sizes of does after fawning (Bartush and Lewis, 1978; Nelson and Mech, 1981; Ozoga, *et al.,* 1982; Beier and McCullough, 1990).

Wiles and Weeks (1986) found that mineral lick locations appeared to influence home range positioning; licks may have influenced home range size during the spring/summer period as well. Doe 4R (the letter "R" designates a radio-equipped animal) was the only radio-collared female with a lick in the center of her home range. Her summer range was the smallest (28 ha) of any animal (Figure 1). Two licks were easily acces-

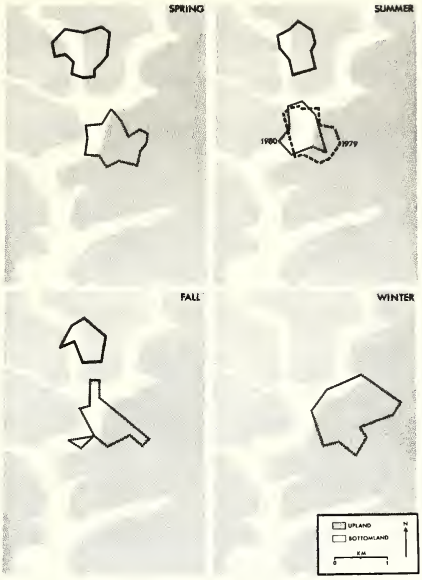

Figure 2. Seasonal home ranges of two radio-collared adult does, 32R (broken lines) and 35R (solid lines), at NWSCC, Indiana, 1979-1980.

sible from any point in her range and eliminated the need to make longer trips to licks. Four deer (Does 21R, 22R, 32R, and 46R) with licks present near their home range boundaries had larger summer areas ($\bar{x}$ = 55 ha, range = 47 - 68 ha) than Doe 4R. Three of these deer had licks located in corners of their home ranges but made little use of regions adjacent to these licks except preceding or following lick visits. Because these areas were used for feeding and resting and not simply as part of a travel route to a lick, they were considered to be inside the animal's home range. No seasonal shifting of home ranges was noted in two deer, Does 32R and 35R, tracked during spring, summer, and autumn in 1979 (Figure 2). Ranges retained a sizable core area that was used each season. Nonetheless, changes in range shape, occurring mostly along range boundaries, were evident over time.

Limited evidence suggests that females at NWSCC may use essentially the same home ranges throughout their adult lives (but see Movements Outside Home Ranges). Doe 32R was radio-tracked during summers of both study years; her ranges were similar during both summers. Sightings of Does 25, 29, and 31 indicated that 1980 home ranges were similar to those of 1979. The most convincing evidence of home range fidelity was exhibited by Doe 35R. This deer was originally tagged in August 1970 as a yearling (F.A. Stormer, pers. comm.) at a point located in the center of her 1979 spring, summer, and autumn home ranges. Another female, Doe 0, was seen consistently in one area during 1979 and 1980 and was resighted in the same locality in October 1986. Except for minor perimeter fluxes, no doe is known to have shifted her home range either

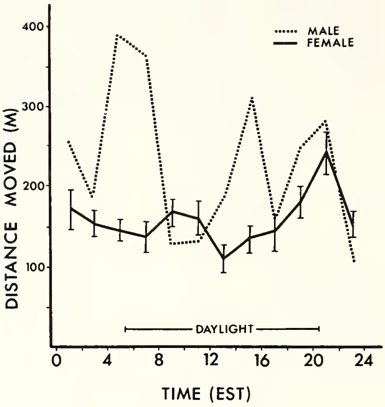

Figure 3. Mean summer movements during 2-hour intervals for six radio-collared female white-tailed deer (n = 38) and one radio-collared male deer (n = 4) at NWSCC, Indiana, 1979-1980.

seasonally or annually. These data on long-term home range stability among females support the findings of others (Tierson, *et al.,* 1985; Beier and McCullough, 1990).

**Summer habitat use.** During summer, four of the six females used bottomland habitat in greater proportion than its relative abundance, while the other two exhibited no habitat preference (Table 3). Concealment qualities of thick vegetation in wooded bottomlands make them a preferred fawning site (Kirkpatrick, *et al.,* 1976). Day and night habitat use patterns were similar for most animals during the summer.

**Activity patterns within home ranges.** The six females were monitored during 38 24-hour tracking periods from June to August. A 3-way ANOVA indicated that there were no significant differences in movements (meters traveled per 2-hour period) among months ($P > 0.75$) or between adults and yearlings ($P > 0.40$); however, movements did vary among the different times of the day ($P < 0.05$). Again, there was no indication that fawning reduced movements of adult does during the first month postpartum. Does were most active near dusk (from 1800-2200 h) with smaller peaks in movement from midnight to 0200 h and from 0800-1200 h (Figure 3). Movements from 2000-2200 h were significantly greater than those of most other periods (Newman-Keuls sequential range test, $P < 0.05$) with the exception of 1800-2000 h, midnight to 0200 h,and 0800-1000 h. Previous studies have shown deer activity in the summer to be high near dusk with other peaks occurring just after midnight (Nelson, 1979), near dawn (Kammermeyer and Marchington, 1977; Beier and McCullough, 1990), and at mid-day (Drolet, 1976). Distances traveled by deer at NWSCC varied considerably within these 2-hour intervals; movements ranged from 0 to at least 410 m in each period. Thus, deer can occasionally be expected not to follow these general activity patterns and may move long distances or remain stationary at any time of the day.

Minimum total distances traveled daily by does averaged 1,890 ± 67 m (range = 1,010-2,640 m). The longest straight-line distance traveled in a 2-hour time period was

Table 3. Summer habitat use patterns as determined by radio locations for six female white-tailed deer at NWSCC, 1979-1980. Percentage of location values marked with asterisk indicate significant habitat selection (Chi-square test, $P < 0.001$).

| Habitat Type | Percentage Available | Percentage of Locations | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 4R | 21R | 22R | 32R[a] | 35R | 46R | Total |
| Upland | 76.3 | 17.0 | 35.7 | 85.5 | 30.6 | 58.4 | 77.1 | 49.9 |
| Bottomland | 23.7 | 83.0* | 64.3* | 14.5 | 69.4* | 41.6* | 22.9 | 50.1* |

[a] Summer habitat use patterns of Doe 32R were pooled for 1979 and 1980.

845 m from midnight to 0200 h. It is generally concluded that males move greater distances than females; for contrast in this area, the only buck that was tracked long enough for comparison moved considerably more than females during 24-hour tracking sessions. He traveled an average of 2,710 ± 250 m per day (n = 4). Peaks in activity occurred near dawn from 0400-0800 h and near dusk from 2000-2200 h (Figure 3). A mid-afternoon peak from 1400-1600 h was most likely an artifact of a single large movement made during that time period.

**Movements outside home ranges.** White-tailed deer at NWSCC made four types of movements from their normal home ranges. Trips to mineral licks were most common and were described by Wiles and Weeks (1986). Other categories of movements included 1) exploratory trips, 2) temporary flights from disturbances, and 3) permanent dispersals.

**Movements outside home ranges: Exploratory trips.** Inglis, *et al.* (1979) noted that nearly 80% of the radio-monitored deer in a Texas study occasionally left their home ranges to make voluntary exploratory trips lasting from 4 hours to several days. Others have noted similar movements among white-tailed deer (Downing and McGinnes, 1975) and black-tailed deer (*Odocoileus hemionus*; Dasmann and Taber, 1956). At NWSCC, trips of this type were rare. Only five exploratory trips were known to have been made by four of the six radio-tagged does. Four of these excursions were short and extended 300-400 m beyond the delineated boundaries of home ranges. A fifth movement differed greatly. Doe 32R traveled 3.4 km southwest of her normal autumn home range on 8 September 1979 and stayed in a 16-ha area of upland hardwood forest for about 4 weeks. Neither a causal factor in her leaving her home range nor any unique feature of the target woodland could be identified that might have attracted and held her. After a month, she returned to her original home range and remained there the rest of the autumn.

**Movements outside home ranges: Temporary flights from disturbances.** Monitoring of three radio-collared deer during the 1979 autumn "either-sex" hunting season indicated that flights from home ranges occurred during gun but not archery hunts. Does 32R and 35R and Buck 34R were located several times each day of hunting. During 7 deer-days (total days that radio-tagged animals were hunted) of bow hunting in October, no "abnormal" deer movements were detected. In contrast, four trips from home ranges occurred during 10 deer-days of shotgun hunting in November and December. The lengths of these trips ranged from 200 m to at least 1 km. Differences in the likelihood of deer to flee their home ranges during the two types of hunts were probably related to the amount of protective cover available and to hunter density and behavior. Forested and brushy habitats became more open toward the end of autumn as leaf fall continued. At the same time, hunting pressure increased dramatically with the number of hunters more than doubling during gun hunts from 1.1 hunters/km$^2$ to 2.7 hunters/km$^2$. Further, shotgun hunters were more likely to disturb deer by hunting while walking than were bow hunters, who preferred still hunting from tree stands or the ground. Noise from shotguns also may have frightened deer.

Two other movements by radioed deer outside their home ranges were recorded. Doe 35R moved 400 m west of her home range for 4.5 h while explosive tests were being conducted at a demolition pit in the eastern part of her home range. Doe 32R traveled a minimum distance of 8.3 km in 15 h during a round trip that took her 3.1 km outside her home range. Free-ranging domestic dogs (*Canis familiaris*) were seen in this doe's home range 2 days earlier and may have chased her from the area.

The kill locations of 12 collared does taken during the autumn hunts on NWSCC were compared with the locations they were observed in the preceding spring and summer. They were recovered at sites averaging 1.72 km (range = 0 - 5.2 km; 42% of kills > 2 km) from their known home range areas. Similar movements among deer at NWSCC were summarized by Kirkpatrick, *et al.* (1976). Downing and McGinnes (1975) were highly suspicious of inferences made about autumn movement patterns of deer that were drawn from hunter returns. As previously discussed, such movements probably represent a mixture of attempts to escape hunting, travel associated with mating activity, and/or temporary large-scale shifts in home range similar to that noted in Doe 35R.

## ACKNOWLEDGMENTS

Indiana Division of Fish and Wildlife funds supported this project. The authors especially thank J.C. Olson, D.J. Case, and R.D. Fahlsing for their assistance in fieldwork, and R.E. Mumford and F.H. Montague for reviewing the manuscript. In addition, the authors would like to thank L. Andrews, H. Thomas, R. Bledsoe, V. Adams, D. Arrington, and the administration and security police of NWSCC for providing information, access, and logistical support. J.D. Pesek assisted with the statistical analyses. This is Journal Paper No. 10,561 from the Purdue Agricultural Experiment Station.

## LITERATURE CITED

Bartush, W.S. and J.C. Lewis. 1978. Behavior of whitetail does and fawns during the parturition period. Proc. Southeastern Assoc. Game Fish Comm. 32: 246-255.

Beier, P. and D.R. McCullough. 1990. Factors influencing white-tailed deer activity patterns and habitat use. Wildl. Monogr. 109, 51 pp.

Byford, J.L. 1970. Telemetrically determined movements of two white-tailed deer fawns in southeastern Alabama. Proc. Southeastern Assoc. Game Fish Comm. 24: 57-63.

Dasmann, R.F. and R.D. Taber. 1956. Behavior of Columbian black-tailed deer with reference to population ecology. J. Mammal. 37: 143-164.

Downing, R.L. and B.S. McGinnes. 1975. Movement patterns of white-tailed deer in a Virginia enclosure. Proc. Southeastern Assoc. Game Fish Comm. 29: 454-459.

Drolet, C.A. 1976. Distribution and movements of white-tailed deer in southern New Brunswick in relation to environmental factors. Can. Field-Natur. 90: 123-136.

Hamilton, R. 1962. Factors affecting dispersal of deer released in Indiana. J. Wildl. Manage. 26: 79-85.

Harvey, M.J. and R.W. Barbour. 1965. Home range of *Microtus ochrogaster* as determined by a modified minimum area method. J. Mammal. 46: 398-402.

Hawkins, R.E., W.D. Klimstra, and D.C. Autry. 1971. Dispersal of deer from Crab Orchard National Wildlife Refuge. J. Wildl. Manage. 35: 216-220.

Holzenbein, S. and G. Schwede. 1989. Activity and movements of female white-tailed deer during the rut. J. Wildl. Manag. 53: 219-223.

Inglis, J.M., R.E. Hood, B.A. Brown, and C.A. DeYoung. 1979. Home range of white-tailed deer in Texas coastal prairie brushland. J. Mammal. 60: 377-389.

Ivey, T.L. and M.K. Causey. 1984. Movements and activity patterns of female white-tailed deer during rut. Proc. Southeastern Assoc. Game Fish Comm. 35: 149-166.

Kammermeyer, K.E. and R.L. Marchington. 1977. Seasonal change in circadian activity of radio-monitored deer. J. Wildl. Manage. 41: 315-317.

Kirkpatrick, C.M., C.M. White, T.W. Hoekstra, F.A. Stormer, and H.P. Weeks, Jr. 1976. White-tailed deer on Crane Naval Ammunition Depot, Indiana. Purdue Univ. Agr. Exp. Sta. Bull. 932, 42 pp.

Larson, J.J., O.J. Rongstad, and F.W. Terbilcox. 1978. Movement and habitat use of white-tailed deer in southcentral Wisconsin. J. Wildl. Manage. 42: 113-117.

Laundre, J.W., T.D. Reynolds, S.T. Knick, and I.J. Ball. 1987. Accuracy of daily point relocations in assessing real movements of radio-marked animals. J. Wildl. Manage. 51: 937-940.

Marchington, R.L. and L.K. Jeter. 1966. Telemetric study of deer movement ecology in the Southeast. Proc. Southeastern Assoc. Game Fish Comm. 20: 189-206.

Michael, E.D. 1965. Movements of white-tailed deer on the Welder Wildlife Refuge. J. Wildl. Manage. 29: 44-52.

Nelson, M.E. 1979. Home range location of white-tailed deer. U.S. Dep. Agr. Forest. Serv., Res. Pap. NC-173, 10 pp.

__________ and L.D. Mech. 1981. Deer social organization and wolf predation in northeastern Minnesota. Wildl. Monogr. 77, 53 pp.

Ozoga, J.J., L.J. Verme, and C.S. Bienz. 1982. Parturition behavior and territoriality in white-tailed deer: Impact on neonatal mortality. J. Wildl. Manage. 46: 1-11.

Progulske, D.R. and T.S. Baskett. 1958. Mobility of Missouri deer and their harassment by dogs. J. Wildl. Manage. 22: 184-192.

Tierson, W.C., G.F. Mattfeld, R.W. Sage, Jr., and D.F. Behrend. 1985. Seasonal movements and home ranges of white-tailed deer in the Adirondacks. J. Wildl. Manage. 49: 760-769.

Wiles, G.J. and H.P. Weeks, Jr. 1986. Movements and use patterns of white-tailed deer visiting natural licks. J. Wildl. Manage. 50: 487-496.

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# ACADEMY BUSINESS

## INDIANA ACADEMY OF SCIENCE EXECUTIVE COMMITTEE MINUTES

## APRIL 24, 1992

President Lovell called the meeting to order at 2:40 pm in room 302 of the L.A. Pittinger Student Center on the campus of Ball State University.

The following members of the Executive Committee were in attendance: Bill Lovell, Wilton Melhorn, Duvall Jones, Ed Frazier, Gene Kritsky, Gary Dolph, and Jim Haddock. Guests included Carl Warnes, Charlotte Boener, Wayne Mueller, Nils Johansen, Walter Hasenmueller, Bill McKnight, and Holly Oster.

1. **Approval of minutes**

   The minutes taken by W. Melhorn on March 14, 1992 were approved after minor editorial and typographical corrections were made.

2. **Report of Executive Officer** (W. Melhorn)

   Wilton brought up several items that were placed under different parts of today's agenda.

   The best place to reach Wilton for the next 4 weeks or so is still his university number, (317) 494-0286; additional numbers are 477-7092 (other office) or 474-4043 (home).

   He is still working at getting his new office in order.

3. **Local Arrangements** (C. Warnes)

   A. Fall Meeting at Ball State. The Fall Meeting will be held primarily in the Cooper Science Complex. The luncheon will be very similar to that served at Evansville. The post-luncheon lecture will be held in the same room as the meal. The Fall Program will be mailed first class, which will cost about $1,400.00. Luncheon will be served on disposable plates at a savings of about $1.00 per person. There will be 2 or 3 shuttle buses available to transport participants from the football stadium to the science complex. Parking close to the meeting site will be prohibitive due to extensive construction. A map will be provided with the program to help visitors.

   Other Comments. The speaker of the year has not been selected yet. Stan Burden, chair of the committee, will be taking care of this. There will be no presidential address or evening banquet.

G. Kritsky will have an explanatory article in the next *Newsletter* on how to fill out the abstract box. This should greatly help Carl Warnes in putting the Program together.

B. Spring (1993) Meeting at Purdue (Melhorn). George Parker is serving as local chair. The meeting will take place sometime during the last 2 weeks of April at the old Purdue Leadership Center (approximately 4-5 miles west of campus and overlooking the Wabash River). The Tippecanoe Parks people now operate this facility. It is unclear at this time as to whether or not the sleeping facilities on the property will be restored and available. The facility is in a rural setting with nature trails suitable for the Saturday field trip.

Parker has also set up a local committee consisting of Bill Chaney, Eileen Kladivko, Larry Bledsoe, and Larry Minchella. Parker will also be checking with the people at Ball State relative to costs for the 1992 meeting.

The exact date of the 1993 Spring Meeting will hopefully be available by the time that the next *Newsletter* goes to press.

C. Fall (1993) Meeting at Purdue. Meeting dates have been set for November 4-5.

D. 1994 Meetings at Indiana University South Bend (Victor Riemenschneider). The Chancellor of Indiana University South Bend has extended an invitation to the Academy to meet on that campus on April 29-30 and November 3-4, 1994.

Larry Barber and Victor Riemenschneider will serve as co-chairs of the Local Arrangements Committee.

A motion was made and seconded to accept the above invitation. Motion approved.

E. 1995 Meetings (G. Kritsky). The Tri-State meeting with the Ohio and Kentucky Academies of Science now appears to be unlikely (see old minutes for historical development).

There is a possibility of holding the 1995 meeting jointly with the Kentucky Academy of Science (meeting site could be in either of the two States at this point).

4. **Treasurer's Report** (E. Frazier)

Ed reported that the Balance on Hand in the Operating Fund is $30,471.27, while in the Restricted Funds, it is $35,276.89 for a total of $65,748.16.

A motion was made and seconded to increase Travel (in the Operating Fund) to $600.00 for the year (from $100.00). Motion approved.

A motion was made and seconded to move $150.00 from the Publications Committee to the Biological Survey Committee. Motion approved.

A motion was made and seconded to receive the report of the Treasurer. Motion approved.

5. **Audit Committee's Report** (Frazier)

The financial records of the IAS for fiscal year 1991 were examined by the Audit Committee (Cleveland and Basu) and appear to be a fair and accurate record of the financial condition of the Academy. It was moved and seconded to accept the report of the Audit Committee. Motion approved.

6. **Amendments Committee** (E. Frazier)

Ed submitted proposed changes to the BYLAWS for the position of Executive Director. (See full text in Addendum to these minutes). If approved by the Council at the Fall Meeting, the changes would become effective on January 1, 1993.

After some pro and con discussion on the role and need of having an Executive Director (= Executive Officer), it was moved and seconded to present the proposal to the Council for its approval at the Fall 1992 Meeting. The Motion was approved after a hand count showed 5 in favor and 1 opposed.

Ed also proposed changes consisting of editorial rearrangement within the BYLAWS (Article VI. Committees and Appointed Positions; see full text in Addendum to these Minutes). A motion was made and seconded to approve the editorial changes for appointed positions with the exception of item 5 (Executive Director), which was handled separately. The Motion was approved.

President Lovell then asked Charlotte Boener to chair an ad hoc Committee to write a job description for the position of Executive Director, assuming that the position will become constitutionally valid through approval by the Council at the Fall Meeting. Charlotte consented and will form a committee consisting of 3 members.

7. **Report of the Nominations Committee** (C. Boener)

Not too much to report at this time. Nominations will be coordinated with the forthcoming *Newsletter.*

8. **Report of the Publications Committee** (B. McKnight)

A. *The Minerals of Indiana.* The Publications Committee is working aggressively with authors on the title *The Minerals of Indiana.* A more formal proposal will be offered at the Fall Meeting.

B. *Indiana: A Natural Perspective.* Bill has recently reopened discussion with

John Gallman, editor of IU Press, on the publication of *Indiana: A Natural Perspective* (95% of the authors are Academy members). Marian Jackson is the editor of this publication. Publication is tentatively proposed for the Fall of 1993. The Publications Committee is proposing to contribute $3,000.00 in funds from their budget to be used to pay for an increased number of photographs in the text. In return, the IAS would be listed as a co-sponsoring contributor on the title page. In addition, the Academy would be allowed to purchase copies at approximately 50% of the retail price ($36.00 - $39.95) for sale to Academy members.

Bill would like to get closure on this proposal by late November 1992 so that the money could be paid to IU Press at that time.

Bill asked for approval to draft a Memorandum of Agreement that would be approved by IU Press and then by the IAS Executive Committee. Upon approval by the latter, the Treasurer would be authorized to sign the Agreement and release the funds.

President Lovell recommended that Bill proceed with the drafting of the memorandum.

C. The Exotic Species Symposium. The publication date for the Exotic Species Symposium is tentatively set for September 1, 1992. The Natural Areas Association is contributing $1,000.00 toward publication costs and will purchase 500 copies at a 50% discount. Bill already has 100 requests for the book and estimates that 200 more will be sold at the Fall Meeting.

Publication costs will run about $20,000.00. There is currently $26,000.00 in the Special Publications Account with $15,000.00 of that earmarked for *Orchids.*

A motion was made and seconded to permit the Publications Committee to spend $20,000.00 from the above account for publication of the Exotic Species Symposium. Motion approved.

9. **Report of the Editor** (G. Dolph)

A. *Proceedings* Update. Volume 100 (3-4): 3 galleys are still out. Gary hopes that Volume 100 will be out in 6 weeks. The Executive Committee and Academy Council Minutes for 1991 will be included in this Volume as well as the Financial Report and the Necrologist's Report.

Duvall asked that lists of new members and financial reports also be included.

Volume 101 (1-2). Gary needs 1 paper to complete this issue.

B. There will be an Editorial Board meeting next November. A main topic will be a discussion of how to tighten standards for publication.

10. **Report of the Membership Secretary** (Jones)

    Membership totals are about the same as last year.

    Duvall is working with a list of the Indiana College Biology Teachers Association to help increase membership and is also identifying individuals within various universities/colleges and large departments to aid in membership recruitment.

11. **Report of the Emeritus Status Committee** (Hopp)

    A motion was made and seconded to approve K.W. Nightenhelser from Arcadia, Indiana, and Donald M. Winslow from Maine for Emeritus Status. Motion approved.

12. **Adjournment**

    A motion was made and seconded to adjourn the meeting at 4:35 pm. Motion approved.

Respectfully submitted,

Jim Haddock, Secretary

## ADDENDUM

## PROPOSED CHANGES FOR EXECUTIVE DIRECTOR

Legend

**Bold-faced** portions are additions to the Bylaws.
Underlined portions are to be deleted from the Bylaws.

**Bylaws**

### Article VI. Committees and Appointed Positions

Sec. 2. The President, and President-elect shall be ex officio members of all committees **except the Nominations and Election Committee. The Executive Director shall be an ex officio member of all committees but without a vote.**

Sec. 3. List of Appointed Standing Committees and Positions

**(5) Executive Director. The Executive Director shall be appointed by the Executive Committee for a three-year term and may be reappointed. The Executive Director shall be responsible to the Executive Committee and work closely with the President. The Executive Director shall develop and administer a Handbook of Operations; coordinate committee chairs, fund raising activities, and relations with other organi-**

**zations; maintain contacts with state agencies; prepare the annual budget with the advice of the Treasurer; and fulfill other duties as may be directed.**

(18) Science and Society Committee. The Science and Society Committee shall consist of nine to twelve members of the Academy, including representatives of industry, serving staggered three-year terms. This committee may maintain a permanent office with a Director and supporting personnel, and is authorized to solicit financial support for its work from foundations or other sources **in coordination with the Executive Director.** This committee shall bring to the attention of the Governor and General Assembly of Indiana the nature and activities of the Academy, indicating that its State Charter and its continued support from the State places upon it the obligation to serve the State in every way possible; to develop procedures for disseminating scientific information and offering scientific advice to citizens of the State through the establishment of a Speaker's Bureau and the use of the various news media; and to mobilize the membership of The Academy in support of these efforts.

## PROPOSED CHANGES FOR EXECUTIVE DIRECTOR AND REARRANGEMENT OF APPOINTED POSITIONS AND COMMITTEES

Legend

**Bold-faced** portions are additions to the Bylaws.
Underlined portions are to be deleted from the Bylaws.
*Italicized* portions are moved or rearranged from the original Bylaws.

**Bylaws**

Article VI. Committees and Appointed Positions

Sec. 2. The President, and President-elect shall be ex officio members of all committees **except the Nominations and Election Committee. The Executive Director shall be an ex officio member of all committees but without a vote.**

Sec. 3. List of Appointed *Positions*

*(4) Editor. The Editor of the Proceedings shall be appointed by the President on recommendation of the Publications Committee and approval of the Executive Committee. The Editor shall be a member of The Academy. The term of the Editor shall be three years, and may be renewed. The Editor shall chair the Editorial Board, serve on the Executive Committee, the Budget Committee, and be responsible for editing and publishing the Proceedings.*

**(5) Executive Director. The Executive Director shall be appointed by the Executive Committee for a three-year term and may be reappointed. The Executive Director shall be responsible to the Executive Committee and work closely with the President. The Executive Director shall develop and administer a Handbook of Operations; coordinate committee chairs, fund raising activities, and relations with other organi-**

**zations; maintain contacts with state agencies; prepare the annual budget with the advice of the Treasurer; and fulfill other duties as may be determined.**

*(6) Necrologist. The Necrologist shall report annually on the loss of members by death and shall offer memorial resolutions.*

*(7) Parliamentarian. In addition to the performance of the regular duties of this office, the Parliamentarian shall make services available, in an advisory capacity, for the formulation of proposed amendments to the Constitution and Bylaws and shall keep these documents up to date by incorporating in them all amendments adopted by The Academy. The Parliamentarian shall serve as Chair of the* **Amendments Committee**.

**Sec. 4. List of Standing Committees**

***(1) Academy Relations to the State Committee. The Academy Relations to the State Committee*** *shall be responsible for all legal and financial relations of The Academy to the State of Indiana.*

***(2) Amendments Committee. The Amendments Committee*** *shall consist of three members, with Parliamentarian as Chair. It shall be responsible for all amendments to the Constitution and Bylaws. It shall be responsible for all amendments and review them in terms of their effect on the present Constitution and Bylaws, including conflicting language and impact on Articles and Sections other than those being amended. In case of any such conflict, the committee on Amendments may revise the language to bring it to agreement withthe present Constitution, and, with the consent of the proposer, present it at the next regular meeting of the Council, or it may be returned to the proposer with suggestions for revision. In no case may an amendment to the Constitution or Bylaws be presented for approval by the Council without being first reviewed by the committee on Amendments. Each proposed amendment must be accompanied by a review statement by the committee on Amendments.*

*(3) Auditing Committee. The Auditing Committee shall be composed of two or three members who shall audit The Academy's financial records annually. It shall review the annual financial report and provide an evaluation of financial records and practices. The committee shall present its report to the Executive Committee no later than April 1.*

*(4) Biological Survey Committee. The Biological Survey Committee shall consist of up to 15 specialists from the fields of botany and zoology who are active in taxonomic and distributional field studies of the flora and fauna of Indiana. There shall be ample representation from both disciplines. It is the function of the committee to promote the study of natural history with an emphasis on the compilation and publication of data on the biota of Indiana. The committee shall advise and provide expertise to The Academy on matters pertaining to the plants and animals of Indiana.*

*(5) Editorial Board of the Proceedings. The Editorial Board shall consist of members selected in consultation with the chair of the Publications Committee and the Editor. The term of each board member shall be 3 years, concurrent with the term of office of the Editor. Board members may be reappointed for additional terms. Editorial Board members*

*will be selected for their knowledge of particular fields of science so that the total board may constitute a broad spectrum of scientific expertise. The function of the Editorial Board shall be to assist and advise the Editor in editing and publishing the Proceedings of the Indiana Academy of Science. The Board will assist the Editor in reading, selecting and refining papers submitted for publication.*

*(6) Emeritus Member Selection Committee. The Emeritus Member Selection Committee shall receive petitions for emeritus membership status and recommend those eligible for this membership status to the Council.*

*(7) Fellows Committee. The* ***Fellows Committee*** *shall be composed of Fellows representing diverse disciplines, serving three-year terms, with some rotation in the terms of the members of the committee. This committee shall present to the Council recommendations for any members to be honored by election to the status of Fellow.*

*(8) Library Committee. The Library Committee shall have charge of all matters concerning the John Shepard Wright Memorial Library and its relation to the State Library.*

*(9) Local Arrangements Committee. The local arrangements Committee shall consist of persons from the host institution. This committee shall make all arrangements for regular meetings of The Academy and its various sections, and shall cooperate with the Program and Invitation Committee in the preparation, printing and distribution of the program and abstracts of the Annual Meeting. Any Symposium or other special program held in conjunction with a regular meeting must be approved by the Executive Committee of the Academy. The Chair of this committee is an ex officio member of the Budget Committee.*

*(10) Membership Committee. The Membership Committee shall promote and encourage membership in The Academy. The President-elect each year shall serve as the committee Chair and the Treasurer shall serve as an ex officio member.*

*(11)* ***Natural Areas Committee. The Natural Areas Committee*** *shall consist of nine members appointed for three-year rotating terms from the fields of botany, geology-geography, and zoology, and with as wide geographic distribution in the State as practicable. This committee shall serve as a channel through which suggestions made by members as to the conservation and preservation of natural areas may be referred to the Council in the form of recommendations.*

*(12) Nominations and Elections Committee. The Nominations and Elections Committee shall consist of three past officers (no current officer may serve). a) The committee shall call for suggestions for nominees for offices to be filled at the next election from the membership by a timely notice in the quarterly Newsletter, and prepare a ballot containing at least two nominees for each position to be filled, except incumbents may be presented unopposed unless there are nominations from the membership. Members of The Academy may nominate any qualified Academy member for any elective office to be vacant the following year, by a petition signed by at least fifteen Academy members in good standing. This petition must be accompanied by a letter from the nominee indicating willingness to serve, and must be received by the Chair of the Nominations and Elections Com-*

*mittee by May 1. In the event that more that two nominees for any one position appear on the ballot, the Committee shall prepare a rating system of voting for those nominees which will permit determination of a majority vote for one nominee for that position. b) Ballots should be mailed at least one month before the return deadline, and mailed by the voting members no later that October 1. c) Returned ballots will be counted by the Nominations and Elections Committee or other designated Academy members. A winning nominee for each position shall be determined by a majority vote of the ballots received. In the event of a tie vote for any position, the vote shall be resolved by the members attending the Annual Meeting. The results of the election shall be reported by the Chair of the committee at the Annual Meeting and in the Newsletter.*

*(13) Program and Invitations Committee. The Program and Invitations Committee shall consist of at least eight members, two Academy members from each of the Local Arrangements Committees of the current, immediate past year and the next year, one member appointed in consultation with the Director of the Junior Academy and the Treasurer, ex officio. Additional members may be appointed if needed. The committee shall receive and solicit invitations from institutions which offer their facilities and services as hosts for meetings of The Academy and shall make recommendations to the Council as to places of future meetings. There should be a clear understanding about the needs of The Academy and financial arrangements with the prospective host institution before any invitation is finalized by The Academy. The Executive Committee should be apprised of any issues in the course of deliberations with the prospective host institution. The committee will also serve in an advisory capacity to the current Local Arrangements Committee, and provide assistance in the printing and distribution of the program and abstracts of the Annual Meeting. The Chair of the committee is an ex officio member of the Budget Committee.*

*(14) Publications Committee. The Publications Committee shall consist of eight members, The Editor, The Chair of the Public Relations Committee, The Chair of the Library Committee, and five members appointed by the President. One of these shall serve as Chair of the committee for a three-year term, which may be renewed. The committee shall determine what is and should be an Academy publication, and shall be responsible for publication of monographs and other special publications, except for the annual program and the Proceedings. The committee shall advise the Editor on matters pertaining to the publication of the Proceedings, but not the selection and editing of the papers to be published.*

*(15) Public Relations Committee. The Public Relations Committee shall provide to the media and the membership notices of meetings and any other information which will acquaint the public with the works of The Academy.*

*(16) Research Fellowship Committee. The Research Fellowship Committee shall select secondary school teachers from among the membership of The Academy to receive fellowships for summer research.*

*(17) Resolutions Committee. The Resolutions Committee shall prepare and submit resolutions at meetings of The Academy.*

*(18) Science and Society Committee. The Science and Society Committee shall consist of nine to twelve members of The Academy, including representatives of industry, serving*

*staggered three-year terms. This committee may maintain a permanent office with a Director and supporting personnel, and is authorized to solicit financial support for its work from foundations of other sources* ***in coordination with the Executive Director.*** *This committee shall bring to the attention of the Governor and General Assembly of Indiana the nature and activities of The Academy, indicating that its State Charter and it continued support from the State places upon it the obligation to serve the State in every way possible; to develop procedures for disseminating scientific information and offering scientific advice to citizens of the State through the establishment of a Speaker's Bureau and the use of the various news media; and to mobilize the membership of The Academy in support of these efforts.*

*(19) Science Education Advisory Committee. The Science Education Advisory Committee should consist of 9 to 12 members, serving 3-year terms with members eligible for reappointment. At least 1/3 of the members should come from the college/university ranks, and at least one member should be a science educator. At least 1/3 of the members should come from the secondary or elementary teaching levels. There should be representation from each of the four major disciplines — biology, chemistry, earth/space science, and physics. The committee will promote quality science teaching in the State of Indiana by such means as suggesting curricular and science textbooks, holding symposia, sponsoring publications, encouraging better training of teachers, generating resolutions for Academy approval, and promoting the importance of science literacy for our society generally.*

*(20) Speaker-of-the-Year Selection Committee. The Speaker-of-the-Year Selection Committee shall select a special lecturer from among the membership of The Academy who will deliver a lecture to the annual meeting of The Academy and to four or five colleges in the State of Indiana during that academic year. The appointment shall be made and the name communicated to the appropriate officers of The Academy by June 1st each year. This program will be supported by The Academy through a special honorarium to the speaker.*

*(21) Youth Activities Committee. The Youth Activities Committee shall consist of twelve members, including the directors of the various youth activities related to The Academy, representing diverse scientific backgrounds and colleges, universities, and secondary schools. The duties of the committee shall be to coordinate Academy sponsored programs in science for middle and secondary schools, to formulate general policies for such activities for which The Academy has accepted some responsibility, and to advise the President on the appointment of persons to lead such activities.*

***Sec. 5.*** *Other standing committees may be appointed by the President, with the approval of the Executive Committee, or by the Council.*

# INDIANA ACADEMY OF SCIENCE COUNCIL MINUTES APRIL 24, 1992

President Lovell called the meeting to order at 4:45 pm in room 302 of the L.A. Pittinger Student Center on the campus of Ball State University.

1. **Approval of the Minutes**

   The Minutes of the November 7, 1991 meeting were approved.

2. **Approval of the Agenda**

   The Agenda for today's meeting was approved, after addition of a few items.

3. **Brief Report of Executive Officer** (Melhorn)

   Volume 98 is still in limbo, as Academy officers have not received manuscripts from the former editor.

   The *Yearbook* is being printed and should be available in a week.

4. **Report of Local Arrangements Committee** (Lovell)

   The 1993 meetings will be held at West Lafayette.

   It was moved and seconded that the Council approve IUSB as the site for the 1994 meeting. Motion approved.

   There has also been a suggestion that we consider a joint Indiana-Kentucky meeting for 1995.

5. **Treasurer's Report** (Frazier)

   Our Operating Fund as of January 1, 1992 stood at $16,512.98 and at the end of the 1st quarter stood at $30,471.27. Additionally, there are restricted funds designated for specific projects (see Addendum).

6. **Report of the Amendments Committee** (Lovell)

   This committee was charged to recommend changes in the Bylaws that would be necessary to formally recognize the position of Executive Officer. The essence of that recommendation is contained in item 5:

   > The Executive Director shall be appointed by the Executive Committee for a three-year term and may be reappointed. The Executive Director shall be responsible to the Executive Committee and work closely with the President. The Executive Director shall develop and administrate a Handbook of Operations, coordinate committee chairs, fund raising activities, and relations with other organizations; maintain contracts with state agencies; prepare the annual budget with the advice of the Treasurer; and fulfill other duties as may be directed.

The Executive Committee will ask the Council for approval of these additions to the BYLAWS (Article VI, Sec. 2 & 3) at the annual Fall Meeting.

The minutes of the December 12, 1987 Executive Committee Meeting show that the 1st draft that dealt with the position was approved. The position originally was considered on a 3-year experimental basis but went four years. We now have our second "interim" [my quotes] Executive Officer, who is 4 months into his 1st term without the position being ratified in the BYLAWS.

There was a concern raised that the title "corresponding secretary" might better reflect the duties of this position as they have been performed in the past (i.e., sending out Agenda's for the President, sending out mailings, etc.).

Another concern raised was that the position might be too powerful relative to that of other offices. Also, the fact that the position is an appointed one means that candidates are not reviewed by the membership as a whole.

Other opinions offered were that this officer should not hold another position in the Academy. Others in the group expressed the importance of having an Executive Director for the sake of having some continuity from one year to the next.

Considerable debate also ensued over how generic the BYLAWS articles and job description should be. Finally, there appeared to be some consensus that both the Articles and job description should be brought forward for action at the same time this fall. Also, the general membership needs to be appraised via the *Newsletter* of the name change for the position from Executive Liaison Officer to Executive Director to avoid confusion.

Charlotte Boener will head an ad hoc committee to write a job description.

7. **Report of the Nomination Committee** (Lovell)

The editor of the *Newsletter* has been soliciting recommendations for people to serve in various offices of the Academy.

8. **Report of the Publications Committee** (McKnight)

*Orchids of Indiana* is being revised by IU Press. Galleys should be available in early July, with publication in the spring of 1993 (hopefully in March).

The Publications Committee has been working with authors at the Geological Survey at IU to develop a *Minerals of Indiana* publication. This will be the first non-biological publication sponsored by the Academy. It will be geared towards the interested amateur as well as the professional. If things proceed well, this book should be released in 1995.

A revised edition of *The Natural Areas of Indiana* is being considered for publication. More color photographs would be included, for example. A one-time contribution to IU Press of $3,000.00 would allow us to be listed as a sponsor on the title page. We would also be allowed to purchase copies at a pre-publication price (reduced rate) which would be available to Academy members. This publication is scheduled for release in the fall of 1993.

Revenues would exceed expenses on this publication according to McKnight. The $3,000 would be transferred laterally to this project from funds already in the budget of the Publications Committee.

Publication of papers presented at the Exotic Species Symposium, which was sponsored by the Academy of Science in October, 1991, is slated for around September 1 of this year. Bill McKnight is serving as editor. This will be a special publication and will not be an issue of the *Proceedings.*

The Publications Committee would like to develop either a 10-year or a 100-year index for the *Proceedings.* If any party is interested in this project, please contact Bill or any member of the Publications Committee.

9. **Report of the Biological Survey Committee** (McKnight)

The Committee is working on a "short list" of native Indiana flowers that are good species to recommend as the State Flower. Public input would be encouraged from flower clubs, people inside and outside of academia, etc. A poster would then be designed that highlighted the half dozen or so contending species. The poster would be circulated to all of the 3,800 4th grade classes in the State. The school children would then make the decision on the "Native Flower of Indiana".

The Biological Survey Committee needs money to produce and mail the posters but is not empowered to solicit for funds. The timetable for the project is to have the posters in the classrooms by the second week of September, 1993. The Survey Committee is asking for Council permission to proceed with the project and for permission to solicit outside funds.

The following Resolution was moved and seconded: that the Council approve the project, direct the Executive Director to work with the Biology Survey Committee to solicit funds, and recommend to the Executive Committee that the Resolution be approved at the next Executive Committee meeting. Motion approved.

10. **Report of Youth Activities** (Dolph)

The new Director for the Indiana Academy of Science Talent Search is Dr. Melissa Warden, a member of the biology faculty at Ball State.

Since the first issue of Volume 100 of the *Proceedings* will likely come in at exact State bid, Youth Activities will be asking for a reinstatement for Science Fair support based on funds saved.

11. **Report of the Editor** (Dolph)

    The last issue of the *Proceedings* came in at approximately $8,400.00. Volume 100 (1-2) is ready to go to press. He is lacking one article before that can happen.

    Minutes of the Executive Committee and Council will again be published in the *Proceedings* as they become available from the secretary.

    New members will be listed by section in the *Proceedings*; Necrology and Financial Reports will also be added. Longer "reports" on noted Indiana scientists will be published through the History of Science Section. The Speaker of the Year report will also be published.

    The Editorial Board will be meeting at the Fall Meeting. A topic of discussion will be ways to tighten up or improve publication standards.

12. **Report of the Membership Secretary** (Jones)

    Membership totals are about the same as last year. Duvall is working with a list from the Indiana College Biology Teachers Association to help increase membership and is also identifying individuals within various universities/colleges and large departments to aid in membership recruitment.

13. **Position Statements of Public Candidates Running for State Offices** (Jones)

    Gene Kritsky has agreed to help obtain position statements (roughly 300 words) from candidates that are running for public office (e.g., State Superintendent of Public Instruction and Governor). These would then be published in the *Newsletter*.

14. **Adjournment**

    A motion was made and seconded to adjourn at 5:45 pm. Motion approved.

Respectfully submitted,

Jim Haddock, Secretary

## ADDENDUM

## INDIANA ACADEMY OF SCIENCE ACCOUNT SUMMARY

| | Beginning Balance 1-1-92 | Revenues YTD | Expenses YTD | Balance on Hand 3-31-92 |
|---|---|---|---|---|
| Operating Fund | $16,512.98 | $18,320.88 | $4,362.59 | $30,471.27 |
| Restricted Funds | | | | |
| *Proceedings* Fund | $324.00 | $478.00 | $0.00 | $802.00 |
| Reprint Fund | $1,932.08 | $110.00 | $461.44 | $1,580.64 |
| Publication Fund | $14,284.94 | $49.90 | $4,100.00 | $10,234.84 |
| Research Grant Fund | $2,056.62 | $0.00 | $0.00 | $2,056.62 |
| Talent Search Fund | $5,471.97 | $3,665.00 | $2,136.67 | $7,000.30 |
| Lilly Library Fund | $6,714.45 | $0.00 | $0.00 | $6,714.45 |
| Welch Fund | $5,885.00 | $419.87 | $0.00 | $6,304.87 |
| Exotic Species Fund | $-77.83 | $721.00 | $60.00 | $583.17 |
| Total Restricted Funds | $36,591.23 | $5,443.77 | $6,758.11 | $35,276.89 |
| TOTAL FUNDS | $53,104.21 | $23,764.65 | $11,120.70 | $65,748.16 |
| | | Deposits | Withdrawals | |
| Checking Account | $9,406.22 | $21,892.90 | $24,120.70 | $7,178.42 |
| Money Market Savings | $12,697.99 | $14,144.70 | $0.00 | $26,842.69 |
| Certificates of Deposit | $31,000.00 | $727.05 | $0.00 | $31,727.05 |
| TOTAL FUNDS ON DEPOSIT | $53,104.21 | $36,764.65 | $24,120.70 | $65,748.16 |

Edward Frazier
Treasurer

# INDIANA ACADEMY OF SCIENCE INFORMAL MEETING OF THE EXECUTIVE COMMITTEE OCTOBER 2, 1992

### Minutes for Informational Purposes Only

President Lovell called the meeting to order at 2:50 pm in room 356 of the Lilly Science Hall at the University of Indianapolis.

The following members of the Executive Committee were in attendance: Bill Lovell, Duvall Jones, Wilton Melhorn, and Jim Haddock. Other members in attendance were Charlotte Boener, Bill Gommel, and David Chesak. There was no quorum present.

1. **Secretary's Report** (Haddock)

   Minutes of the April 24 meeting to be moved for approval at the November 5, 1992 meeting at Ball State.

2. **President's Comments** (Lovell)

   We are moving forward and making good progress at this time.

3. **Executive Officer Comments** (Melhorn)

   A. 1994 Meeting. The Chancellor of IU South Bend has extended a formal invitation for the IAS to meet on their campus in 1994, and the Academy has accepted.

   B. 1993 Meetings at Purdue. Wilton will be attending a planning meeting on October 16 along with George Parker and other members of the Local Arrangements Committee.

   C. 1995 Meetings. Wilton talked with Gene Kritsky and there is still a possibility of having a joint meeting with Kentucky. The discussion centered around a Fall Meeting to be held at the Owensboro Convention Center.

   A Spring 1995 Meeting was not discussed. A separate committee would need to be appointed to organize this meeting (perhaps in southern Indiana).

   D. Certificate of Appreciation. A certificate of appreciation was presented to Sallye Hunter on September 11 for her help with the *IAS Yearbook* over the last several years.

   E. Winslow holdings. There is still lots of material to be sorted.

4. **Editor's Report** (Melhorn for Dolph)

Gary reported that Volume 100 (3-4) was published September 18, 1992.

5. **Local Arrangements Committee** (Melhorn for Warnes)

Meeting times for committees on Thursday November 5:

| | |
|---|---|
| Publications | 1:00 pm |
| Executive | 2:30 - 5:00 pm |
| Council | 5:00 pm |

Program should be in the mail by early October.

Abstracts are to be camera-ready (we need to improve the quality of submitted abstracts).

6. **Publications Committee** (McKnight)

A. *Orchids of Indiana.* Final page proofs are due to Bill soon.

B. Exotic Species Symposium. Twenty-one papers have been received. Page proofs are ready for twenty of the twenty-one, and Bill is still hoping to have this publication ready by late October for the Natural Areas Meeting.

C. Ten-year Index. Charlotte Boener has volunteered to do a 10-year index (Volumes 91-100). She needs Volumes 98, 99, and 100. This may be published in disc form rather than in hardcopy. If it is a hardcopy, it may be merged with a volume of the *Proceedings* or may be as a separate.

D. Coordination with the State Library. Bill discussed at some length the need to improve communications with the State Library relative to maintaining Academy materials and publications there. Some recommendations included meeting with the Library Director and resurrecting the IAS Library Committee. President Lovell encouraged the Publications Committee to bring forth recommendations for consideration.

7. **Amendments Committee** (Gommel)

A. Bill made copies of the Constitution available (not including the recent suggested changes).

B. There was a suggestion to change the title "Executive Director" to "Executive Secretary" or to "Executive Officer."

The Bylaws (printed in the *Newsletter*) will be presented at the November Council Meeting.

The original term (i.e., "Executive Director") will be presented to the Council, and an Amendment could be proposed at that time regarding the name change.

8. **General Discussion**

The last few minutes of this informal meeting involved considerable discussion as to whether the changes pertaining to the "Executive Director" should be incorporated into the Constitution or the Bylaws. The general consensus was that since it is an appointed position rather than an elected one, it should be placed in the Bylaws.

Other minor amendments were suggested and will undoubtedly be brought up at the forthcoming Council Meeting.

# INDIANA ACADEMY OF SCIENCE EXECUTIVE COMMITTEE MEETING
## OCTOBER 2, 1992

A quorum was reached at 4:17 pm with Ed Frazier's arrival. President Lovell then formally brought the committee to order.

1. **Secretary's Report** (Haddock)

The minutes of the April 24, 1992 meeting were presented for approval after typographical changes were made. Motion approved.

2. **Treasurer's Report** (Frazier)

A. Remuneration expenses for travel, etc. The procedures for applying for remuneration should be part of an information packet given to new officers, etc.

B. There was a motion to accept the Treasurer's Report. It was approved, and the report was accepted.

3. **Old Business**

A. Report of the *ad hoc* Committee on the Executive Director's Position (Boener). Charlotte presented a report entitled "Responsibilities of the Executive Director." A motion was made to receive her report. Motion approved.

President Lovell asked the Executive Committee to be prepared to discuss the report and to consider its inclusion in the *Handbook of Operations* at the next meeting. Her committee also submitted a letter to the President to express their recommendations for long-range planning.

Considerable discussion ensued relative to whether or not the position has actually been established and approved by the Council. The general consensus was that the effort to improve the workings of the Academy through the creation of the position of Executive Director has been a long and torturous one that has involved four administrations. This is due to the fact that for the first 3 years, the position was experimental in nature. The majority felt that the move to permanency is an important one and necessary if the Academy is to flourish. There were several opinions expressed that the Academy Officers individually, and collectively as the Executive Committee, have acted in good faith relative to bringing this project to fruition.

4. **New Business** (Melhorn)

   A. A.J. Phinney Memorial. The late A.J. Phinney was a charter member of the Academy. His grave, in Muncie, is unmarked.

      President Lovell will donate $250.00 from the President's Fund to help defray the expenses for his marker.

   B. 1993 Yearbook. Wilton has proposed sending the 1993 Yearbook to all members.

   C. Return postage for Ballots and Dues Notices. Paying for return postage has been suggested as a way to improve returns by the membership.

5. **Adjournment**

   It was moved and seconded that the Committee adjourn at approximately 5:00 pm. Motion carried.

# INDIANA ACADEMY OF SCIENCE EXECUTIVE COMMITTEE MINUTES
## NOVEMBER 5, 1992

The meeting was called to order by President Lovell at 2:30 pm in Room CL118 of the Cooper Science Building at Ball State University.

The following Executive Committee members were in attendance: Dolph, Frazier, Haddock, Jones, Kritsky, Lovell, and Melhorn.

Additional Academy members present were: Boener, Gommel, Hasenmueller, Jensen, McKnight, Mueller, Oster, Parker, Rothrock, Townsend, and Warnes.

**Approval of Minutes**

The minutes of the October 2, 1992 meeting were accepted after correction of typographical errors.

## Old Business

1. **Local Arrangements** (C. Warnes)

   One hundred fifty-eight members preregistered; 440 lunch tickets have been sold so far, and we have seating capacity for 462.

   Concerns. How do we handle the large numbers of students in the Junior Academy? We need to communicate earlier and more effectively with the person selected as Speaker of the Year so that the person is better acquainted with the luncheon procedure.

2. **1993 Program** (G. Parker)

   Spring Meeting. This meeting will be held April 23-24 at Ross Camp (about 8 miles west of the Purdue campus). Facilities include A-frame sleeping quarters with bunk beds (bring our own bedding and towels). The banquet on Friday and the breakfast on Saturday will be held there. Jim Gammon will be the guest speaker. All three field trips (Geology, Ornithology, and Natural Resources) will start from the camp.

   Fall Meeting. This meeting will be held November 4-5 in the Student Union at Purdue University. Arrangements will be made for a projected 600 attendees.

   George presented an initial proposed budget. Income was projected at $11,784.00 with expenses being $12,935.00 for a deficit of $1,151.00. It was suggested that local industry be approached to help defray the $1,200.00 cost for coffee and donuts. Another suggestion involved asking the University to absorb some of the coordination and supervisory services expense inasmuch as Purdue will receive a direct benefit from the visit of 300 promising high school students, the vast majority of whom will be attending college after graduation from high school.

   Miscellaneous. It was recommended that we consider separating the charge for registration from that for lunch.

3. **Report of the *ad hoc* Committee on Duties of the Executive Officer** (C. Boener)

   This Committee's report was originally submitted and received at the October 2, 1992 Executive Committee meeting. Hopefully, this report will be included in the *Handbook of Operations*. Its intent is to summarize the commonly perceived duties of the Executive Officer.

   A motion was made and seconded to accept the entire report of the committee (i.e., approval of the recommendations).

   A motion was made to amend the document by changing the title of the position from Executive Officer to Executive Secretary. The motion failed.

The motion to accept the entire document passed.

## New Business

1. **Report of the Nominations Committee** (C. Boener)

| | |
|---|---|
| President-Elect | Wayne Mueller |
| Bonding Committee | Charles Hammond |
| Research Grants Committee | Nelson Shaeffer |
| Academy Foundation | Stan Burden |

Other comments. Combine the ballot with the Fall Meeting Program to save postage (however, send the Program 1st class).

2. **Treasurer's Report** (E. Frazier)

A summary of the Treasurer's Report is given below. The report was accepted.

| | Beginning Balance 1-1-92 | Revenues YTD | Expenses YTD | Balance on Hand 9-30-92 |
|---|---|---|---|---|
| Operating Fund | $16,512.98 | $25,042.68 | $13,052.22 | $28,503.44 |
| Total Restricted Funds | 36,591.23 | 34,804.74 | 31,915.60 | 39,480.37 |
| Total Funds | 53,104.21 | 59,847.42 | 44,967.82 | 67,983.81 |

3. **Report of the Academy Foundation** (F. Guthrie)

The Foundation consists of three accounts under the management of the INB Trust Company. The status of each account is summarized briefly below:

A. Initial account. The assets consist of money market funds, U.S. Treasury Notes, etc.

| | |
|---|---|
| Market value | $75,191 |
| Est. Ann. Income | $4,030 |

B. John S. Wright Fund. This fund originally evolved from a gift of Eli Lilly & Co. stock. Today, it is composed of Lilly as well as other stocks, Treasury notes and bonds, and short term funds.

| | |
|---|---|
| Market Value | $1,914,752 |
| Est. Ann. Income | $83,927 |

C. Invested Income Account. This fund is based on the income derived from the Wright Fund, and because it is used to sponsor many Academy activities (publications and research grants, for example), it must have a high degree of liquidity. Therefore, funds are primarily invested in a money fund account.

| | |
|---|---|
| Total Asset Value | $216,804 |
| Est. Annual Income | $9,036 |

The Academy is in good shape financially. The trustees have a goal of increasing income by 20-25% over the next couple of years to enable the IAS to support new and expanded Academy programs.

4. **Report of the Resolutions Committee** (J. Haddock for M. Morse)

Whereas: The members of the Indiana Academy of Science are deeply grateful for the invitation to hold the 108th annual meeting of the Academy on the campus of Ball State University; and

Whereas: The administration, faculty, staff, and students of Ball State University have cooperated admirably in providing their facilities, resources, and support for this 108th annual meeting of the Indiana Academy of Sciences; be it

Resolved: That the Academy members here assembled express their sincere appreciation of Dr. John Worthen, President of Ball State University, for all the courtesies that have been extended to the Academy during this meeting. We are especially grateful to Dr. Carl E. Warnes and Dr. Larry R. Ganion, chairpersons of the local planning committee, to the members of the committee, and to other facilitators for the arrangements of the entire program and for the comfort and conveniences provided Academy members and guests. We also express our sincere thanks to all Academy members who organized and participated in activities associated with this 108th annual meeting of the Indiana Academy of Science.

5. **Report of the Director of Public Relations** (G. Kritsky)

A. The candidates for governor and state superintendent were solicited for their views on science education. No comments were received.

B. A motion was made and seconded to increase the 1992 *Newsletter* budget by $350.00 to cover postage and mailing of the December 15th issue. Motion passed.

C. Report on Kentucky Academy of Science Meeting. It was poorly attended (150+), and the overall quality of papers was poor in Kritsky's opinion.

The question was raised as to whether or not to continue with a joint meeting with the KAS in 1995, with the possibility of meeting in Louisville. The consensus was to continue talking with Kentucky.

6. **Editor's Report** (G.Dolph)

   Progress of Proceedings. Volume 100 (3-4) came out in September. Volume 101 (1-2) will hopefully be out before Christmas. Volume 98 is at the publisher!

   Questions. Will the financial report be in the published minutes, and, if so, in how much detail? Will local arrangements costs be published to help future committees?

7. **Publications Committee** (B. McKnight)

   A. We have had a great increase in book sales ($1,300.00 received in the last 10 days, for example), and Bill will need help in packaging and mailing.

   B. The committee established a goal approximately two years ago of being able to be completely independent of the Academy for funding of book publications based on income generated from sales.

   (Some of these are primary sales where we published the book and others are secondary sales where we purchase books and resell them).

   C. *Orchids of Indiana* is due out soon.

   D. *Plants of the Chicago Region.* Do we want to reissue this book which is now out of print? We can make about a $25,000.00 profit on it.

8. **Report of the Biological Survey Committee** (B. McKnight and P. Rothrock)

   A. State Flower Project. Bill gave an update of this project. Twelve species of native flowers have made the "short list," and posters exhibiting these species will be mailed to all 4th grades in the State. Eventually, they will be voting for their choice of State Flower.

   Some seed money (about $1,000.00) will be needed from the Academy to help in this project, and this request will be submitted to the Budget Committee in December.

   A motion was made and seconded to authorize continuation of the project and to seek financial support from outside of the Academy. Motion approved.

9. **Relation of Academy to the State** (B. McKnight)

    A. Bill expressed some concerns relative to our relationship with the State Library. Preservation of our approximately 4,000 sq. ft. of space initially secured for us by John Wright. According to contractual agreements their association can be terminated by either the Library or the Academy with a year's notice.

    B. The book exchange program needs to be studied. For example, the Academy incurred a $12,000.00 cost for exchanges involving the *Butterflies* publication. What did we get in return?

    H. Oster mentioned that there is no exchange program involving other institutions within the borders of Indiana. Considerable discussion followed. It was suggested that the Committee on Relation of the Academy to the State be revitalized and be given the charge of addressing the above concerns. Another suggestion was that a strategic Planning Committee be instituted to study the matter.

10. **Adjournment**

    It was moved and seconded to adjourn at 4:45 pm. Motion approved.

Respectfully submitted,

Jim Haddock
Secretary

# INDIANA ACADEMY OF SCIENCE
# 1992 YEAR END FINANCIAL REPORT

| | Beginning Balance 1-1-92 | Revenues | Expenses | Ending Balance 12-31-92 |
|---|---|---|---|---|
| OPERATING FUND | | | | |
| Dues | | $24,638.00 | | |
| Interest | | $2,373.87 | | |
| Contributions | | $833.00 | | |
| Spring Meeting | | $782.00 | $938.23 | |
| Annual Meeting | | $7,299.00 | $8,749.77 | |
| Officers Expenses | | | $5,992.67 | |
| Operating Expenses | | | $4,699.84 | |
| Financial Expenses | | | $812.00 | |
| Newsletter Expenses | | | $3,515.29 | |
| Library Operations | | | $2,843.04 | |
| Publication Comm. | | | $35.33 | |
| Speaker of the Year | | | $700.00 | |
| AAAS Representative | | | $449.04 | |
| Biological Survey | | | $473.25 | |
| Youth Activities | | | $3,362.50 | |
| Operating Fund Total | $16,512.98 | $35,925.87 | $32,570.96 | $19,867.89 |
| RESTRICTED FUNDS | | | | |
| Proceedings | $324.00 | $11,153.23 | $11,332.25 | $114.98 |
| Reprints* | $1,932.08 | $971.00 | $1,775.44 | $1,127.64 |
| Publication | $14,284.94 | $9,676.92 | $10,566.80 | $13,395.06 |
| Research Grants** | $2,056.62 | $41,976.00 | $41,154.55 | $2,878.07 |
| IAS Talent Search | $5,471.97 | $3,676.00 | $4,185.70 | $4,962.27 |
| Lilly Library | $6,714.45 | $.00 | $58.33 | $6,656.12 |
| Welch Fund | $5,885.00 | $483.87 | $.00 | $6,368.87 |
| Exotic Species | $-77.83 | $1,721.00 | $60.00 | $1,583.17 |
| TOTAL FUNDS | $53,104.21 | $105,583.89 | $101,704.03 | $56,984.07 |
| FUNDS ON DEPOSIT | | Deposits | Withdrawals | |
| Checking Account | $9,406.22 | $107,440.79 | $115,468.48 | $1,378.53 |
| Money Market Savings | $12,697.99 | $70,867.42 | $61,000.00 | $22,565.41 |
| Cert. of Deposit | $31,000.00 | $2,040.13 | $.00 | $33,040.13 |
| TOTAL FUNDS DEPOSITED | $53,104.21 | $180,348.34 | $176,468.48 | $56,984.07 |
| FOUNDATION ACCOUNTS | Carrying Value 12-31-91 | | | Carrying Value 12-31-92 |
| John S. Wright Fund | $744,790.99 | | | $742,083.71 |
| Invested Income Fund | $184,757.74 | | | $216,104.60 |
| IAS Foundation Fund | $67,401.31 | | | $71,015.96 |
| TOTAL FUNDS | $996,950.04 | | | $1,029,204.27 |

* Includes $1,000 honorarium for Editor of IAS Proceedings Volume 98.

** Includes 44 senior grants and 17 high school grants.

Audited February 27, 1993 Edward L. Frazier, Treasurer

Proceedings from the Indiana Academy of Science
(1992) Volumne 101 p.345-346

# NECROLOGY

FRANK N. YOUNG
INDIANA UNIVERSITY

## FREDERIK J(OZEF) BELINFANTE

| | |
|---|---|
| The Hague, Netherlands<br>January 6, 1913 | Gresham, Oregon<br>1991 |

Belinfante received his B. and B.S. degrees from the Rijksuniversitate in Leyden, Netherlands, and the Ph.D. in 1939. He migrated to the United States in 1948 and was naturalized in 1955. He taught physics at several U.S. universities. He was invited to and participated in various international physics meetings in France, Poland, the Netherlands, Mexico, and the United States. He was the U.S. representative to the Internacia Scienca Asocio Esperantista from 1949-1957. He was a fellow of the American Physical Society and a member of various other professional societies. Belinfante was author of various scientific publications in English and Esperante.

## PAUL BENDER

| | |
|---|---|
| Springs, Pennsylvania<br>June 26, 1899 | Goshen, Indiana<br>September 14, 1990 |

Paul Bender received the A.B. degree in physics from Hesston College in 1921 and the M.S. and Ph.D. degrees from the University of Iowa in 1925 and 1931, respectively. He taught at Goshen College as professor of physics until his retirement. He was a key figure in the development of the general science program at Goshen. He served as President of the Indiana Association of Collegiate Registrars. During World War II, Bender served as director of two civilian conservation camps for conscientious objectors. He also served as interim dean of Hesston College for three years in the 1960's. At his memorial service at Goshen College, he was characterized as a meek but highly able man. Friends and colleagues at Goshen share in the rich heritage he left.

## LESTER I(RVING) BOCKSTAHLER

| | |
|---|---|
| Spencer County, Indiana<br>July 22, 1895 | Evanston, Illinois<br>May 2, 1991 |

Lester Bockstahler received the A.B. degree from Indiana University in 1920, the M.A. in 1921, and later received the Ph.D. degree from Northwestern University in 1924. He did postgraduate work in Germany in 1927. Earlier, he served as Second Lieutenant in the U.S. Army in 1917-1918 and later with the U.S. Government in Germany in 1952-54. He was the recipient of the Certificate of Merit from the Physics Club of Northwestern in 1959. He was a member of Phi Beta Kappa and several professional societies.

## BARBARA SHALUCHA

Springfield, Vermont
December 9, 1915

Bloomington, Indiana
May 10, 1992

She received the B.S. and M.S. degrees in horticulture in 1937 and 1938 from the University of Vermont and the Ph.D. degree from Ohio State University in 1947. She came to Indiana University later in 1947 and founded the Garden and Nature Center the next year.

Barbara received support for her program at Indiana University from individuals, garden clubs, the city, and the State. In 1985, she was appointed a delegate by the China-U.S. Scientific Exchange to lecture on botanical gardens in Beijing, Hanjing, Suzhow, Wuxi, and Hangzhou. In 1963, she was made a member of the advisory board of the Young Garden Council in Washington, D.C. Hilltop Garden received a presidential citation from the Garden Clubs of Indiana and from the National Council of State Garden Clubs. Shalucha herself was the recipient of the first Youth Gardening Award from the Civic Garden Centers in 1983 and was elected to the executive board of that organization the same year. In 1983, she was also appointed by the Governor of Indiana to the Food and Agricultural Advisory Council of the White River Park Development Commission.

The gardening experience that Barbara provided for many children in the Bloomington area was rewarded by the pleasure she experienced when watching children grow. She once said that one of the most exciting things about the Hilltop program was realizing that her friends' faces were coming back to her attached to miniature bodies. Her contributions to gardening in the University community will be long remembered.

# MANUSCRIPT REVIEWERS

## VOLUME 101, NUMBERS 1-2 AND 3-4

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